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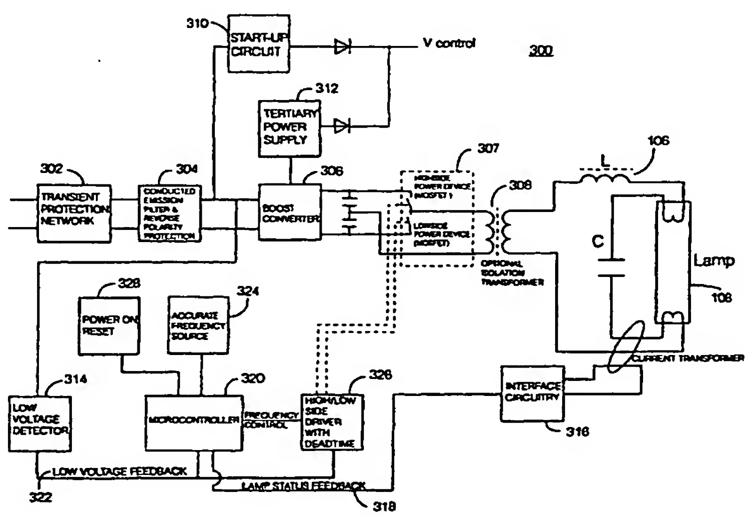

(57) Abstract: The present invention relates to a lamp driver unit for, in particular, fluorescent lamps. The lamp driver unit comprises an inductive and capacitive output stage which is driven by a microcontroller that controls very precisely the frequency of the signals used or applied to the L/C network. The microcontroller uses a counter and a stable high frequency oscillator to produce a very stable and accurate frequency signal for application to the L/C resonant network which, in turn, results in closely controlled lamp operating parameters. Advantageously, such precise control of the operating frequency results in, for example, significantly improved lamp life, operating conditions, consistent output intensity and colour and significant flexibility in being able to accommodate changes in lamp drive parameters.

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For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

LAMP DRIVER UNIT AND LAMP

The present invention relates to a lamp and driver unit, and, more particularly, to a lamp and driver unit implemented using a microcontroller.

A fluorescent lamp driver unit as is well known within the art comprises electronic circuitry that is capable of converting electricity from a power supply source into a waveform suitable for driving a fluorescent lamp. The power source may be either AC or DC.

The design of fluorescent lamp driver units is intended to take into account a plurality of design objectives. These design objectives include, for example, improving lamp life, improved mean time between failures, improved number of attainable lamp start up cycles without significant lamp deterioration, high operating efficiency, negligible audio noise, various safety features, reduced component count, reduced manufacturing costs and lighting environment enhancing features.

A fluorescent lamp driver unit is available from Excil Electronics Limited, Ripley Drive, Normanton, West Yorkshire, WF6 1QT. For example, Excil Electronics manufactures and markets a fluorescent lamp driver unit known as an "Excil 388 Series" lamp driver unit.

It is an objective of the present invention to provide an improved lamp driver unit that at least mitigates some of the problems of prior art lamp driver units.

Accordingly, a first aspect of the present invention provides a lamp driver unit comprising a software controlled microcontroller arranged to execute software to generate an output waveform having a selectable one of a plurality of predeterminable frequencies, a lamp drive means comprising at least one inductor and at least one capacitor arranged to

produce a drive signal for the lamp in response to receiving the output waveform; the output waveform being derived from a programmable counter that is driven using an oscillator, the selectable one of the plurality of predeterminable frequencies being determined by count value of the programmable counter in response to data values contained within the software executed by the microcontroller.

Advantageously, the embodiments of the present invention allow the operating points or operating frequencies to be selected and set independently of each other. In contrast the operating frequencies or operating points of many prior art arrangements do not have such independent control.

Preferably, an embodiment provides a lamp driver unit in which the microcontroller derives the output waveform from an oscillator waveform produced by an oscillator.

Further, an embodiment provides a lamp driver unit in which the microcontroller comprises means for dividing the oscillator waveform by a predeterminable divisor.

Still further, an embodiment provides a lamp driver unit in which the means for dividing comprises a programmable counter arranged to vary the count thereof in response to the oscillator waveform and the output waveform is produced in response to an output signal of the programmable counter.

An embodiment provides a lamp driver unit in which the divisor is determined according to a predeterminable frequency.

A further embodiment provides a lamp driver unit in which the predeterminable frequency is determined according to lamp type.

A still further embodiment provides a lamp driver unit in which the predeterminable frequency is determined according to

a stage of operation of a lamp.

Yet another embodiment provides a lamp driver unit in which the stage of operation is one of pre-heating, generating a strike voltage and maintaining an arc current waveform.

Preferably, an embodiment provides a lamp driver unit in which the predeterminable frequency is selected from a plurality of frequencies.

Preferably, an embodiment provides a lamp driver unit wherein the inductive and capacitive elements of the lamp drive means comprises an inductor connected in series with a capacitor, and means for receiving the lamp such that, in use, the lamp can be connected in parallel with the capacitor.

It will be appreciated that a common problem with prior art designs is that the inner glass wall of the lamp adopts a blackened appearance close to the electrodes. The blackened appearance is caused by excessive stress to the electrodes particularly during the strike process resulting in electrode emissive material being jettisoned from the electrode surface onto the lamp inner glass wall. The appearance is undesirable and loss of emissive material from the electrodes results ultimately in lamp failure.

Accordingly, an embodiment of the present invention provides a lamp driver unit comprising means for heating the lamp electrodes prior to application of a strike voltage. Preferably, the lamp electrodes are heated to the point of thermionic emission.

Advantageously, the means for pre-heating ensures a free flow of electrons from the electrodes prior to arc discharge (lamp striking). This, in turn, significantly reduces the amount of the electrode emissive material jettisoned from the electrodes onto the lamp inner glass wall during striking.

Preferably, the pre-heat period is fixed and is closely controlled. In a preferred embodiment, the pre-heat period is between 0.5 and 2 seconds.

It will be appreciated that one source of premature lamp failure is excessive electrode stress.

Accordingly, an embodiment of the present invention provides a lamp driver unit comprising means for ensuring the arc current waveform has a predeterminable crest factor. Still further, a preferred embodiment provides a crest factor of 1.4.

A further source of premature lamp failure results from electrode wear.

Therefore, an embodiment provides a lamp driver unit in which the drive signal comprises a substantially fully symmetrical arc drive current waveform. It will be appreciated, in the absence of the lamp as a non-linear load, that the waveform produced by the LC circuit would be a sine-wave. However, due to the non-linearities of the lamp, that sine-wave become distorted slightly. Therefore, the arc drive current waveform is a near-sine wave current waveform, that is, a substantially sine wave waveform. Therefore, a near sine-wave waveform is that waveform which results from application of a sine-wave to the non-linear lamp load.

Advantageously, such a substantially symmetrical drive waveform ensures equal gas conduction in both directions within a lamp and ensures substantially equal electrode self-heating during arc discharge and corresponding substantially equal electrode wear. This prevents mercury vapour migration within the lamp which is commonly manifested as light output from only one end of a lamp.

A problem often associated with fluorescent lamp operation is the generation of audio frequency noise. Any

such noise pollution adversely affects the environment within which the lamp is situated.

Accordingly, an embodiment of the present invention provides a lamp driver unit operable at a predeterminable drive frequency. Preferably, the drive frequency is substantially between 30 kHz and 50 kHz according to lamp style.

Advantageously, the choice of drive frequency, in particular in conjunction with the near-sine arc current waveform, dramatically reduces audio noise generated during lamp operation. Furthermore, such a choice of frequency reduces RFI emitted from the lamp wiring.

It will be appreciated that lamp life is dependent upon the correct level of arc discharge current flow. It is the arc discharge current flow that generates self-heating within the electrodes during lamp operation when a pre-heating current has been removed or reduced.

Accordingly, an embodiment of the present invention provides a lamp drive unit providing means for maintaining a substantially stable lamp arc current. The substantially stable lamp arc current is maintained at a predeterminable value notwithstanding variations in power supply voltage.

It will be appreciated that the appropriate lamp arc current is dependent upon the lamp type and lamp operating parameters. Preferably, an embodiment of the present invention provides a lamp drive unit in which the lamp arc current is held to within ±6% of a preferred lamp arc current level indicated by corresponding lamp manufacturer data.

Advantageously, the self-heating process results in a free flow of electrons from the electrodes into the lamp gas due to thermionic emission and reduces electrode erosion.

Maintaining the lamp arc current to within predeterminable tolerances also advantageously ensures constant light output over a predeterminable input power supply range.

A source of premature lamp failure can often be attributed to excessive component stress within the product.

Accordingly, an embodiment of the present invention provides a lamp driver unit operable at predeterminable power conversion efficiencies. Preferably, the operating efficiencies are at least 84% and, more preferably, are between 84% and 90%. Advantageously, such high operating efficiencies result in low internal component temperature changes which, in turn, results in reduced component stresses and improved reliability of operation.

During a power failure, emergency lighting is often provided by a DC power source. The improved efficiency of operation of the lamp driver unit according to an embodiment of the present invention enables, for a given DC power source, extended periods of emergency lighting or, for a given design period of emergency lighting, a battery rating reduction to be realised.

Maintenance and testing of installed conventional lamp driver units often carries a risk of electric shock.

Accordingly, an embodiment of the present invention provides a lamp driver unit comprising means arranged to provide a floating lamp drive output. Preferably, the means arranged to provide a floating lamp drive output comprises an output transformer wound for 2 kV primary to secondary isolation. The risk of electric shock is advantageously reduced.

It will be appreciated that there are many ways in which a lamp and lamp driver unit may be inadvertently damaged. For

example, the following may result in lamp driver electronics failure: misconnection of the lamp, DC reverse polarity, failure of the lamp, open circuit lamp, short circuit of the lamp arc for an indefinite period and short circuit of either lamp electrode for an indefinite period. Typically, conventional prior art lamp driver units rely upon fuses to provide protection against the above. It will be appreciated that the provision or use of such fuses increases component count and manufacturing and maintenance costs.

Accordingly, an embodiment of the present invention comprises means for electronically providing at least one protection feature.

An embodiment of the present invention provides a lamp driver unit comprising means for maintaining a substantially stable arc discharge current within the lamp.

Such a substantially stable arc discharge current provides relief from colour bias and assists in ensuring consistent illumination levels and colour between lamps.

It is often the case, in the event of a failed lamp, with some electronic ballast designs and conventional electro-magnetic lamp driver systems, that multiple re-strikes will be attempted. Clearly such failed multiple re-strikes are undesirable in that they provide an unpleasant environment and unnecessarily expend power.

Accordingly, an embodiment of the present invention provides a lamp driver unit comprising means for preventing attempted re-strikes in the event of a failed lamp. Advantageously, long term continuously attempted re-strikes in the event of lamp failure are avoided.

A further embodiment provides a lamp driver unit comprising a cut-out means for inhibiting the use of a lamp upon detection of a falling supply voltage or a supply voltage

that is below a predetermined level. Preferably, the cut-out means is provided with some hysteresis to assist in providing a "clean" cut-out, that is to say, to avoid flickering as a failing supply voltage varies.

It is often the case with conventional driver units that the lamp or driver electronics may be damaged as a consequence of surges and transients present on a power supply.

Accordingly, an embodiment of the present invention provides a lamp driver unit comprising transient and surge suppression means.

Embodiments of the present invention will now be described, by way of example only, with reference to the accompanying drawings in which:

figure 1 illustrates a lamp driver unit according to an embodiment;

figure 2 shows an L/C circuit used in a lamp driver stage of an embodiment;

figure 3 depicts schematically a lamp driver unit according to an embodiment;

figure 4 shows a circuit diagram of an embodiment; and

figure 5 shows a flow chart of an embodiment.

An embodiment of a lamp driver unit, for example a fluorescent lamp driver unit, according to the present invention comprises two independent functional stages, as can be seen from figure 1. The first stage 102 is a power supply stage, that is, a step-up boost converter. The second stage 104 comprises the lamp driving circuitry. The step-up boost converter 102 increases an input supply voltage, V_{input}, to a much higher voltage and operates in a closed loop mode so that the output voltage is maintained substantially constant irrespective of variations in the input voltage, V_{input}.

In the case of an AC power supply being connected to the boost converter 102, the boost converter 102 operates on a full wave rectified but unsmoothed version of the AC supply and is power factor correcting. Such a power factor correction stage employs active correction techniques so that the current waveshape consumed from the AC power supply is substantially identical to the waveshape of the applied voltage, which is usually a sine wave. Such a power factor correction stage results in low power supply harmonic distortion and a high power factor, typically exceeding 0.95.

The high voltage output produced by the boost converter 102 is known as a link voltage, Vlink. The link voltage is, typically, in the region of between 250 V DC and 380 V DC. The stable, regulated link voltage is output from the boost converter 102 and input to the lamp driver stage 104. Operating the lamp driver stage 104 using the stable regulated link voltage produced by the boost converter 102 assists in ensuring or maintaining a substantially constant light output over the full permissible input power supply voltage range. The lamp driving stage 104 produces a square wave drive waveform using a symmetrical power drive circuit configuration that is described hereafter.

The square wave drive waveform is applied either directly or indirectly via an isolation transformer to an L/C resonant circuit 106 which acts as the lamp drive interface.

The L/C resonant circuit 106 is used to produce the three operating conditions required by the lamp 108; namely, pre-heating current, strike voltage and lamp operating arc current. It will be appreciated that the nature of the resonant circuit results in the lamp arc current operating under near sine wave current drive conditions.

Referring to figure 2, there is shown schematically the L/C resonant circuit 106 together with the lamp 108. According to an embodiment of the present invention, the L/C

resonant circuit 106 is driven using a variable frequency, fixed amplitude square wave 202. The capacitance of capacitor C is preferably fixed as is the inductance of the inductor L. The three stages of ignition, that is, electrode pre-heat, strike voltage generation and arc current regulation are realised by varying the drive frequency of the square wave 202. It will be appreciated that the resonant frequency of the L/C resonant circuit 106 is fixed at some predeterminable value given by.

$$Fr = 1/2\pi \sqrt{(L.C)}.$$

The frequency of the square wave 202 is arranged such that it is preferably always above the fixed resonant frequency of the L/C resonant circuit 106. The drive frequency can be varied under the control of a microcontroller as described hereafter.

During an electrode pre-heat period, the square wave frequency is arranged to be high and well above the resonant frequency of the L/C resonant circuit 106. For example, the square wave frequency, F_p, is initially 59.5 kHz for a 58 Watt, T8, 1500 mm lamp. It will be appreciated as a result of the high drive frequency, relative to the resonant frequency of the L/C circuit 106, that voltage magnification is low and the voltage generated across the lamp arc, V_{arc}, is also low and insufficient to cause gas breakdown and strike the lamp. However, during this stage, at frequency, Fp, current flows via the lamp electrodes 204 which causes pre-heating of these electrodes. The pre-heating current and duration of the pre-heating period is arranged such that thermionic emission from the electrodes results. Both the requisite pre-heating current and pre-heating period can usually be obtained from or derived from electrode emission constants available from manufacturers' data sheets.

An embodiment is provided in which the pre-heat period has a duration of between 0.5 seconds and 2 seconds. An embodiment is also provided in which the pre-heat current may be predetermined to be between 0.2 and 1.1 amps according to a given lamp. It will be appreciated that for a given model of lamp the pre-heat current and/or pre-heat period are substantially constant.

After completion of the pre-heating period, the operating frequency of the square wave 202 is reduced gradually, under the control of the microcontroller, over a predeterminable period, typically 100 milliseconds, to a strike frequency, Fs. The strike frequency is arranged to be significantly closer to the resonant frequency of the L/C resonant circuit 106 than the pre-heating frequency. Preferably, the strike frequency is arranged to be above the resonant frequency. It will be appreciated that initially the lamp arc impedance will be high and does not load the resonant circuit. Accordingly, at the strike frequency, significant voltage magnification occurs and the resultant voltage developed across the capacitor, C, is high and known as the strike voltage. The strike voltage is that voltage which is sufficient to cause gas breakdown and thereby strike the lamp. It will be appreciated that the strike voltage will also vary according to the model of lamp utilised.

Once the lamp 108 has struck, the arc impedance drops considerably and an arc current flows which results in light output. The drop in impedance across the lamp causes severe damping of the L/C resonant circuit which is arranged to result in a reduction of the arc voltage to the normal operating voltage for the lamp. The arc current for the lamp is principally determined by the value of the inductor L and the operating frequency.

Once the lamp 108 has struck, the operating frequency of the square wave 202 is changed to F_{run}, which is the frequency

required for correct operating arc current. The operating frequency is either equal to or greater than the strike frequency. This provides further independent means of determining or controlling the arc current rather than relying solely upon the value of the inductor L. This is because arc current is determined by the impedance of L ie $X_L=2\pi F_{run}L$. Therefore, both F_{run} and L can influence X_L. Preferably, the running frequency, F_{run}, will be identical to the strike frequency Fs, but not essentially so.

The above frequencies are derived via software division of a signal output from a high accuracy frequency source such as, for example, a ceramic resonator or crystal. The high frequency accuracy results in extremely accurate lamp drive parameters, such as pre-heat current, strike voltage and arc current, which are all frequency dependent, being derived from the L/C resonant network 106. The accuracy of controlling these parameters assists in improving lamp life from the start up cycle through to the normal operating discharge.

Advantageously, implementing the lamp driver stage 104 using a microcontroller allows different lamps to be accommodated simply by making software changes.

Referring to figure 3, there is shown a block diagram of an embodiment of the present invention illustrating the functional elements of the embodiment. Typically, an embodiment of the present invention may be utilised to drive fluorescent lamps on, for example, a railway carriage. However, it will be appreciated by those skilled in the art that the present invention is not limited to application within the railway industry and can equally well be used in any other environment.

The schematic diagram 300 illustrates a transient protection network 302 which receives as an input a supply voltage, V_{input}. The input voltage is typically derived from a vehicle supply voltage. The transient protection network 302

provides protection against transients and surges in the vehicle supply.

The transient protection network 302 is coupled to a conducted emission filter and reverse polarity protection circuit 304 which provides for protection against incorrect connection of the vehicle supply to a boost converter 306 and driver circuit in general. The conducted emission filter and reverse polarity protection circuit 304 also prevents switching noise from the boost stage and driver stage being passed to the input power supply wiring and assists in ensuring compliance with European EMC regulations, such as ENV 50121-3-2.

The boost converter 306 is coupled to the conducted emission filter and reverse polarity protection circuit 304 and arranged to produce a regulated and stable high voltage output.

The boost output feeds a push/pull driver stage 307 consisting of high and low side power devices. The high and low side driver devices are under the control of a controller 326. Optionally, an isolation transformer 308 receives the output of the driver stage and couples it to the L/C resonant circuit 106 including the lamp 108.

A start-up circuit 310 is coupled to the output of the conducted emission filter 304. The start-up circuit is utilised to provide a low voltage power supply for powering the control electronics and is only used for a brief period at system power-up. Once the boost converter is operational, the low voltage power supply for the control electronics is provided by the tertiary power supply 312 which is derived from the boost converter.

It will be appreciated that Vcontrol is the power supply for the control electronics of an entire embodiment. Vcontrol is initially provided by the start-up circuit and then by the

boost converter tertiary supply. The two diodes enable mixing of the start-up and tertiary power supplies.

Preferably, an embodiment of the present invention also comprises a low voltage detector 314 arranged to provide or detect insufficient vehicle supply power levels or a failing vehicle power supply.

Interface circuitry 316 is arranged to provide, via a lamp status feedback signal 318, an indication to the microcontroller 320 of the status of the lamp.

The microcontroller 320 also receives a low voltage feedback signal 322 from the low voltage detector 314.

As indicated above the L/C circuit and lamp are driven using an accurately controlled high frequency square wave signal 202. The square wave signal 202 is derived from a very accurate frequency source 324 and supplied to the L/C circuit via the microcontroller 320 and a high/low side driver 326 with dead time.

Preferably, a power on reset circuit 328 is coupled to the microcontroller 320 and is arranged to reset the microcontroller 320 at power-up.

Referring to figure 4, there is shown in greater detail schematic circuitry of an embodiment of a lamp driver unit according to the present invention. The driver unit 400 comprises two independent stages. As described in relation to figure 1, the first stage is a step-up boost converter 102 which increases the input supply voltage, V_{input}, to a regulated link voltage, Vlink, that is arranged to be substantially constant over the full range of permitted input supply voltage, V_{input}.

The second stage is the lamp driver stage which operates using the stable link voltage produced by the step-up boost converter 102. By utilising a regulated link voltage the lamp

light output is substantially constant over the full power supply variation of the input voltage, V_{input}.

The lamp driver stage 104 comprises a switched mode square wave generating circuit 402. The square wave generating circuit consists of U4 and drive mosfets Q4 474 and Q5 476, which feed the lamp via the L/C resonant circuit 106. The resonant circuit comprises an inductor L3 and a capacitor C17. Preferably, the inductor has an inductance of 0.985 mH. Preferably, the capacitor is rated 15 nF/1600V.

DC power, V_{input}, is coupled to the lamp driver unit at junction J1 (404) and junction J2 (406). Junction J1 is the positive supply connection and junction J2 is the ground connection. The input voltage is applied to the transient protection and filter networks 302 and 304. The transient protection and filter network comprises a 2 amp, 100μH inductor L1 408, a 630V, 10N capacitor C1 410 and a voltage dependent resistor M1 412 or metal oxide varistor available from Harris-semiconductors, part no. V130LA20A. The protection/filter network is coupled via a fuse F1 414, a common mode choke L8 416, a reverse polarity protection diode D23 418 and a differential mode choke L2 420 to the boost converter circuitry 102.

Preferably, the fuse 414 is a 2.5A anti-surge fuse, the common mode choke 416 is a RN 124 available from Schaffner Components, the reverse protection polarity protection diode 418 is a UF5406 available from General Instruments, and the differential mode choke L2 420 is a 100 uH, 0.91A inductor. It will be appreciated that inductors L8 and L2 reduce emissions conducted onto the DC supply wiring in compliance with European EMC standard EN50121. Inductor L8 416 is a dual winding device and is designed for common mode interference suppression. Inductor L2 420 is a single winding device and is designed for differential mode interference suppression.

The capacitor C1 410 also serves to reduce differential mode interference.

It will be appreciated that the incoming power supply, V_{input}, may be contaminated with high voltage transients of both positive and negative polarity. Therefore, a fast recovery device is selected for the reverse polarity protection diode 418 to ensure adequate blocking of the negative transients during which the device will be reserve biased.

The boost converter 102 comprises an inductor L7 422 (windings pin 2 to pin 6), a mosfet Q3 424, diode D5 426 and a capacitor C9 428. Mosfet Q3 may be an IRF740 available from International Rectifier, diode D5 may is a BYT03-400 available from SGS Thomson.

The boost converter 102 operates in a closed loop mode with a regulated output under the control of U1 430. U1 is a TL4941D available from Texas Instruments. U1 428 operates in a fixed frequency, variable duty cycle mode. The variable duty cycle output from U1 is derived from pins 9 and 10 and used to control the resultant output voltage by varying the ratio of the *on* to *off* time of the mosfet Q3 424. The duty cycle is adjusted in response to the feedback from the boost converter output voltage.

In the case of an AC power supply, the boost converter 102 operates on a rectified but unsmoothed version of the incoming power supply voltage, V_{input}, and provides power factor correction. Such a system may operate in variable frequency mode.

It will be appreciated that energy is stored in inductor L7 422 when mosfet Q3 424 is switched on and released via diode D5 426 into capacitor C9 428 when mosfet Q3 424 is switched off. The boost converter 102 operates in this discontinuous mode for the majority of power supply means. Therefore, the energy stored within inductor L7 422 while

mosfet Q3 424 is "*on*" is completely exhausted by means of transfer to capacitor C9 428 when mosfet Q3 424 is "*off*". The output voltage of the boost converter 102, that is to say, the voltage across capacitor C9 428, is maintained at a substantially constant level by closed control which is achieved by varying the duty cycle of the mosfet Q3 424 in response to feedback from the output of the boost converter 102.

It will be appreciated that when mosfet Q3 424 is on, pin 6 of inductor L7 422 is pulled low and the inductor L7 422 is effectively connected across the DC power supply with pin 2 at +Ve and pin 6 at -Ve (ground). Accordingly, the current of inductor L7 422 increases linearly with time and energy is stored within inductor L7 422. When mosfet Q3 switches off, the energy stored within inductor L7 422 must be released. As a result, pin 6 of inductor L7 422 swings positively in polarity with respect to pin 2. The positive swing continues until diode D5 426 is forward biased. The point at which diode D5 426 is forward biased is determined by the voltage across the capacitor C9 428, which is in turn set by the negative feedback, variable duty cycle control system, and is selected to be a value that is considerably above the DC input voltage, V_{input}. It can therefore be appreciated that voltage step up occurs with a substantially constant output voltage resulting across capacitor C9 428, which is referred to as the link voltage as described earlier.

U1 430 contains an amplifier and variable duty signal pulse width system. The device U1 430 is arranged to compare the voltage feedback signal of the link voltage with a fixed voltage reference and to adjust the drive duty cycle according. If the link voltage is low, the duty cycle is increased. If the link voltage is high, the duty cycle is decreased. A stable voltage reference is generated by Z2 which is compared within U1 to a proportion of the link voltage derived via R11, R12, R13 and R4. The control loop is

satisfied when the reference voltage and the derived proportion of the link voltage are equal. The duty cycle is adjusted to attain such equality. It will be appreciated that since a proportion of the link voltage is compared to the reference, the system has voltage gain determined by:-

Boost Gain = 1+((R11 + R12 + R13)/R4)

Hence, the link voltage is determined by the above resistor values.

The operating frequency of U1 is determined by R8 and C4 and given by the approximate relationship F= 1.1/(R8.C4) and is chosen, in an embodiment, as approximately 55 kHz.

Two internal uncommitted transistors form the output of U1 (pin 8/9 and pin 10/11) and in this embodiment are wired in parallel as emitter followers with collectors tied high to the low tension power supply line "Vcontrol". The variable duty cycle output present at pin 9/10 (uncommitted transistor emitters), therefore requires a pull-down which is accomplished by R14. As the duty cycle output (pin 9/10) has high positive drive but only a passive pull down, the signal is buffered in the negative drive polarity by Q2 but simply passed on in the positive polarity by D4, to form a signal suitable for driving Q3.

During normal operation, the low tension power supply line "Vcontrol" is provided by a tertiary winding on the boost inductor (L7 pin 7/10/11). However, the tertiary winding voltage is not initially present at power-up and an alternative means of generation of "Vcontrol" is required until boost oscillation occurs. The alternative source is provided by start-up circuitry R69, Z1, Q1, R70 and D2. This configuration forms a simple emitter follower power supply with an output voltage set by a zener diode Z1 448. The diode D2 452 forms a means of override such that the tertiary winding supply may assume or take over the provision of

"*Vcontrol*" when the voltage exceeds that of the start up circuit 444.

The tertiary winding has two taps that are selected by inclusion of either of diodes D24 454 and D25 456. The selection of the taps allows a wide range of link voltages to be accommodated as differing link voltages will result in different voltages across the main winding (pins 2 and 6 of inductor L7 422) and hence across the tertiary winding.

Tertiary rectification is provided by diodes D24 454 or D25 456. Smoothing is provided by capacitor C45 458 which is rated 1 uF/35V. An emitter follower regulated power supply 460 is arranged to accommodate changes in the input power supply voltage, V_{input}, since the tertiary voltage is proportional to the main winding voltage which is, in turn, dependent upon the input power supply voltage, V_{input}. Schottky diode D26 462 allows mixing of the tertiary derived voltage with the start-up circuit voltage such that the highest voltage acts as the "*Vcontrol*" supply. After start up, the "*Vcontrol*" supply is provided by the tertiary derived voltage.

It will be appreciated that although U1 430 does have an internal voltage reference, this internal voltage reference is insufficiently accurate to act as a boost converter closed loop control reference. However, the internal reference is made available for external use at pin 14 and is used as a +5V power supply. It can be seen that a 50 volt, 100 nanofarad capacitor C35 464, a 10 Ohm, 0.1 Watt resistor R64 466 and a 50 volt, 100 nanofarad capacitor 468 provide filtering and de-coupling for the +5V supply.

The link voltage, that is the voltage across capacitor C9 428, is passed to the lamp driver stage 104 via a BLM 41-P7505 inductor L4 and a 1 kV, 1 nanofarad capacitor C38 472. Inductor L4 470 is a ferrite bead manufactured by Murata, part no. BLM41-P750S. The inductor 470 and capacitor 472 form a high frequency filter to prevent high frequency ringing,

typically present at the boost converter 102 output, from progressing into the lamp driver stage and hence the lamp wiring.

The lamp drive power stage 402 comprises a pair of mosfets Q4 474 and Q5 476 configured in a half bridge, push/pull mode. The square wave output from the half bridge configuration, which can be observed at test point nine, drives the lamp via the L/C resonant circuit 106 comprising a 0.985 mH inductor L3 478 and a 1,600V, 15 nanofarad capacitor C17 480. In all modes of operation, that is preheat, lamp strike and arc current regulation, the half bridge output frequency is arranged to be above that of the fixed resonant frequency of the L/C circuit 106. This ensures that the half bridge load always appears inductive and results in zero-volt mosfet switching.

Zero-volt mosfet switching advantageously reduces device dissipation by ensuring that the drain/source voltage is zero when the device is switched on thereby reducing switching losses. The two output mosfets 474 and 476 are driven under the control of U4 482 which is a dedicated combined high and low mosfet driver device. In an embodiment U4 can be realised using an IR2104S. Mosfets Q4 474 and Q5 476 are operated in anti-phase under the control of U4 482. To prevent cross conduction of the output of mosfets Q4 474 and Q5 476, U4 incorporates a built in "*dead time*". The dead time period is a short period in every drive cycle when neither mosfet device is "*on*". Without "*dead time*", there would be drive overlap, where, for a short duration, mosfets Q4 474 and Q5 476 would be in the "*on*" state. This would result in high transient current peaks consumed from V_{link} and possible device failure. In an embodiment the dead time is preferably 500 nsec.

In addition to preventing cross conduction, inclusion of dead time also allows mosfet commutation or "zero-volt switching". Assuming, initially, that mosfet Q4 474 is

conducting, the half bridge output would be in the high state. When the drive to mosfet Q4 474 terminates, the inductive nature of the load swings the half bridge output negatively. This occurs during the dead time. The negative swing continues until caught by the intrinsic body diode of Q5. This action is known as commutation as at the end of the dead time when mosfet Q5 476 switched "*on*" the drain/source voltage thereof is already zero. The reverse happens on the next cycle with mosfet Q4 474 switching with zero drain/source voltage.

A snubber network 484, comprising a 1 watt, 10 Ohm resistor and two 2 kV, 1 nanofarad capacitors C13 and C14 arranged in a series, limits the slew rate of the half bridge output and thereby reduces RFI during commutation. The snubber network 484 is arranged to ensure that slewing of the output has ceased prior to the end of the dead time thereby ensuring zero-volt switching.

Device U4 482 is a dedicated high/low side drive device. It accepts as an input at pin 2 a single square wave and from this generates the drive signals for the high and low side device mosfets Q4 474 and Q5 476. The U4 device 482 also arranges the dead time between the high and low mosfet conduction. It will be appreciated that since both devices of the half bridge configuration are "N" channel, the upper mosfet device Q4 474 requires a gate drive voltage that is higher than the voltage present at the drain of mosfet Q4 474 to achieve saturation. Without such a condition being satisfied, the device would operate in a follower mode. Satisfying this condition is achieved using a charge pump comprising a diode D16 486 and a 63 volt, 100 nanofarad capacitor C26 488. Pin 8 of device U4 482 is the power supply pin for the upper 474 drive stage. When the half bridge output is low (Q5 476 on), capacitor C26 488 is charged to "*Vcontrol*" via diode D16 486.

The voltage across capacitor C26 488 is used to provide pin 8 of device U4 482 with a voltage that is higher than that of the drain of mosfet Q4 474 when that mosfet is "*on*" as the voltage of the capacitor C26 is added to that of the half bridge output. Such an arrangement ensures sufficient drive voltage for the gate of mosfet Q4 474 and ensures full saturation. The drive of the lower mosfet Q5 476 is readily available from Vcontrol.

The device U4 482 comprises a shut down function at pin 3. If pin 3 is pulled to a low state, the drive of both output mosfets 474 and 476 is inhibited. This function is described in further detail hereafter.

The output of the half bridge stage is used to drive the lamp via the L/C network comprising inductor L3 478 and capacitor C17 480. The L3/C17 network is driven using a variable frequency, fixed amplitude square wave.

In an embodiment, the inductor L3 is realised using an industry standard "RM10" core/bobbin style inductor. A low loss ferrite material is preferably utilised such as, for example, a Philips 3C85. It should be appreciated that care should be taken during design/calculation of this component to ensure freedom from saturation particularly during the generation of the strike voltage where current flow is high. Freedom from saturation is achieved by selection of a core with an adequate gap and high volume. There are certain lamp types that require a high strike voltage, and an RM12 core may be required thereby giving greater core volume. During strike voltage generation, the 3C85 material may be operated to a peak flux density of substantially 300 mT as this will drop considerably when the strike voltage ceases and the arc current begins to flow. The drive frequency of the L3/C17 resonant network is governed by software running within the microcontroller U3 490 and a crystal device X1 492. The software is arranged such that the driving frequency appears

on U3 device line "PB0", that is, pin 6. The driving frequency is then passed directly to the half bridge driver device U4 482 at pin 2.

Preferably, the software is used to realise a multi-strike attempt function whereby if the lamp fails to strike on the first attempt, further attempts will be made. This function is realised by repeating the pre-heat/strike voltage cycle with appropriate pauses between attempts. Typically, a period of 1 second is allowed between strike attempts. The number of attempts is configurable and under software control.

Furthermore, if the lamp does not strike after a predetermined number of attempts, for example three attempts, the lamp driver unit enters a shut down mode and lamp driving attempts are halted. This arrangement ensures that annoying flickering of life expired lamps associated with conventional electro-magnetic ballast systems is eliminated. Furthermore, the output stage is also shut down to prevent continuous heat dissipation in the output stage which could lead to failure of the lamp driver unit.

Preferably, a lamp struck detector 494 provides an indication of a successful lamp strike. A measure of arc current feedback is provided at CT1/CT2 via a current transformer 496. The current transformer 496 comprises three independent, single turn windings, two of the windings are the primary circuit and are wired in series with the connections to one lamp electrode "Elect 2" and the remaining winding, the secondary circuit, used to provide feedback signal CT1/CT2.

It will be appreciated that passing both connections of one lamp electrode via the primary windings results in an output from the secondary winding that represents arc current, that is, the light producing current which flows between the two lamp electrodes. During preheat, the output of the secondary winding is zero since the two primary windings carry equal but opposite currents. The secondary output produced is

a current which therefore requires a load resistor R22 to produce a useful voltage at CT1/CT2. In an embodiment, resistor R22 is realised using a 1/8W, 2R2 resistor.

Signal CT1/CT2 is applied via a low pass filter 498 to a comparator arrangement comprising an LM2903D, a 0.1W, 150R resistor R15 and 1 nF/50V capacitor C12. The output of the comparator, pin 7, is an open collector type and has a pull down ability only. Therefore a 0.1W, 10K resistor R21 is provided. The output, $\overline{STK}$, of the comparator is converted to a steady DC level via the arrangement of resistors R21, R23 and capacitor C15. In an embodiment, the resistor R23 is a 0.1 Watt, 1K0 resistor and the capacitor is rated 1 uF/25V. Without the network of R21, R23 and C15, $\overline{STK}$ would normally be high in the absence of arc current and a square wave in the presence of an arc current. The resistor-capacitor network R23 and C15 maintains a logical high state in the absence of an arc current and a logical low state in the presence of an arc current.

$\overline{STK}$ is passed to the microcontroller port input PB5 (pin 11) and can be read internally by software.

In a preferred embodiment, there is provided a low voltage detector 500 which is used to prevent attempted drive during low power supply voltage conditions. Additionally, the low voltage detector 500 is operable to produce a clean shut down of the lamp during a slowly falling supply voltage which prevents erratic behaviour exhibited by many prior art driver units.

The low voltage detector 500 comprises hysteresis. On a rising supply voltage, the low voltage detector will permit lamp operation when a higher threshold "pick up" voltage is reached. However, on a falling supply voltage, lamp operation is inhibited when the supply voltage falls below a lower threshold "drop out" voltage. The hysteresis also provides

tolerance of power supply ripple. In an embodiment, for a 110V DC nominal Railway power supply, the higher threshold "pick up" voltage is 67V and the lower threshold "drop out" voltage is 60V. The low voltage detector 500 comprises a U2A 502 and associated components. A portion of the DC supply voltage is derived and filtered by an RC network comprising resistors R29, R30 and capacitor C19 and applied to the comparator 502 for comparison with a fixed reference voltage, V_{ref}. Hysteresis is realised by a resistor-diode network comprising a 0.1W, 6K8 resistor R28, an LL4148 diode D10 and a 0.1W, 18K resistor R32.

The comparator output, at pin 1, drives a buffer stage transistor Q6 504 via interface circuitry comprising a Zener diode Z3 506, a 0.4W 3k3 resistor R33 508 and a 0.1W, 47K resistor R24 510. The purpose of the Zener diode Z3 506 is to prevent spurious operation of the transistor Q6 504 due to erroneous operation of the comparator 502 under low supply voltage conditions.

The low voltage detector 500 also comprises means for providing a uni-directional delay function 512 such that when the pick up voltage is exceeded a small delay follows before operation begins to allow board initialisation. The pick-up voltage is that voltage at or above which the low voltage detector circuitry permits circuit operation. However, for a falling supply voltage, the operation is arranged to terminate substantially immediately if the supply voltage falls below the drop out threshold.

In a preferred embodiment, the means for providing the uni-directional delay function comprises a 0.1W 10K resistor R25, a 0.1W, 680K resistor R26, a capacitor C18 rated 1 uF/25V, a diode D1 and a mosfet Q7.

A signal is generated on line "VDU" 514 by a transistor Q8 516 which is passed to the microcontroller 490 and read internally by software. If the VDU line is low then normal

operation of the board continues. However, if the VDU line is high, this provides an indication that the low voltage detector 500 has determined that the operation of the lamp driver unit should be terminated.

The microcontroller 490 comprises means to shut down the operation of the lamp driver stage under software control. Shutting down the lamp driver stage is accomplished via the shutdown pin of device U4 482 (pin 3) and the signal $\overline{SD}$. The $\overline{SD}$ function shuts down when the line is in a logical low state. Normal operation follows when the line is in a logical high state.

The $\overline{SD}$ line is controlled via microcontroller 490 port line PB4 (pin 10) and, due to the action of transistor Q9 518, a low state at port pin 10 results in a high state of the $\overline{SD}$ line only if the output, VDU, from the low voltage detector circuit is high.

It will be appreciated that the low voltage detector 500 is arranged to produce a logical high signal on line VDU 514 when an adverse input voltage, V_{input}, has been detected. It will be appreciated that this arrangement, based around transistor Q9 518, ensures that $\overline{SD}$ is low if "VDU" is low irrespective of the microcontroller instruction.

In a preferred embodiment, the microcontroller 490 is coupled to a power up reset circuit for supply a power reset signal to the microcontroller. In a preferred embodiment, the power up reset circuit comprises a 0.1W, 47K resistor R34 520, a 50 volt, 100N capacitor C23 522 and a diode D11 524.

Optionally, to reduce the risk of electric shock from the lamp driver unit, galvanic isolation is provided between the lamp driver stage and the lamp output. Galvanic isolation ensures that the lamp drive output is floating notwithstanding the status of the power supply input, V_{input}. It will be

appreciated that there is no DC electrical continuity between the lamp drive output and the input power supply. However, a small high frequency AC path may exist due to capacitive coupling.

In a preferred embodiment, galvanic isolation is achieved by the use of a 1:1 ratio isolation transformer inserted between the half bridge push/pull driver stage 402 and the output resonant circuit 106. The transformer primary winding should preferably be AC coupled which is achieved, in an embodiment, by use of two series connected capacitors arranged across "Vlink" and configured to create a "Vlink/2" AC coupled centre point reference. The primary winding of the isolation transformer is connected, at one end, to the half bridge output (TP9) and the other end of the primary winding is connected to the centre tap between the series connected capacitors. This arrangement ensures freedom from any DC component that is present at the primary winding. The snubber network 484 is, preferably, retained on the primary (driver stage) side and connected directly across the primary winding. The secondary winding output is connected, at one end, to inductor L3 478 and the remaining end is connected to the output circuit AC coupling capacitor C16 526. In an embodiment of the lamp driver unit the capacitor C16 is a 250V, 470n capacitor.

A suitable isolation transformer, in an embodiment of the lamp driver unit, could be a transformer based around an assembly such as, for example, an ETD29. A low loss core material should preferably be used such as a Philips 3C85 or Philips 3C90 core. If such cores are used, the primary winding turns quantity should be calculated such that the resultant flux does not exceed 200 mT to 250 mT, which is an upper limit of flux. Ensuring that the flux does not exceed 200 mT to 250 mT ensures freedom from saturation and results in a low loss core.

It will be appreciated that inclusion of an isolation transformer has a further advantage in that a small core gap may be provided which will serve to increase primary energy storage during open circuit lamp conditions. This will aid commutation of the output stage resulting in reduced dissipation of mosfets Q4 and Q5 under "no lamp" conditions until software shutdown occurs.

Another advantage of the inclusion of an isolation transformer is that the device may be wound to provide a step up or step down function. The former being utilised to combat low "Vlink" conditions due to a lack of step up dynamic range within the boost function.

The microcontroller 490 is employed as a management means for the lamp driver unit. The microcontroller 490 produces or controls the output to the L3/C17 network at the appropriate operating frequencies and can thereby fully control the lamp drive parameters pre-heat, strike voltage generation and operating arc current.

Additionally, the microcontroller 490 is employed to perform complete sequencing of the lamp driver unit and to perform continuous monitoring tasks. A summary of the micro-controller functions is shown below:

(a) control of pre-heat current by control of operating frequency;

(b) control of strike voltage by control of operating frequency;

(c) control of operating lamp arc current by control of operating frequency;

(d) control of pre-heat duration;

(e) implementation of multi-strike attempt system;

(f) continuous monitoring of arc current flow instigating re-strike if lamp extinguishes;

(g) monitoring of supply voltage in conjunction with external hardware; and

(h) ability to shut down the lamp driver stage in the event of strike failure.

Referring to figure 5, there is shown a flowchart which illustrates the flow of control of the microcontroller 490. It will be appreciated that the software for running the microcontroller 490 is stored and addressed internally.

The generation of the appropriate operating frequencies is accomplished by the use of an internal eight-bit timer/counter in conjunction with an interrupt routine. The counter is advanced by a clock signal which is internally derived by frequency division of an external 20 MHz crystal 492. Within the software, a predetermined preset count is loaded into the counter and the counter is then varied, that is, advanced or decremented,via the internally derived clock signal.

The microcontroller 490 is configured such that when overflows occurs, an interrupt request is generated which causes an immediate jump to an interrupt service routine. The interrupt service routine is arranged to toggle the frequency output port line PB0 (pin 6) each time the interrupt routine is called. It will be appreciated that such an arrangement constitutes a programmable counter.

Additionally, the interrupt routine is arranged to reload the counter with the preset count. As is well known within the art, the state of the microcontroller registers are pushed onto and pulled off a stack of the microcontroller at the beginning and end of the interrupt routine respectively.

The counter/timer operates substantially independently and the preset count is used to determine the operating frequency produced. It will therefore be appreciated that the generation of the different frequencies required for pre-heat, strike voltage and arc current regulation is attained by loading appropriate pre-set count values into the counter, that is, the generation of different frequencies is under software control and can be altered readily to accommodate different lamps.

The microcontroller device, in a preferred embodiment, is realised using a PIC16C620A and uses an eight bit counter with a clock derived from a division by four of the 20 MHz crystal signal. Although this provides an adequate resolution for most applications, a greater resolution may be achieved by using a microcontroller comprising a counter having a greater number of bits and a device where the counter/timer clock is derived from a higher frequency source.

Referring to figure 5, the main routine begins when the external power up reset period, set by the RC time constant resulting from the combination of resistor R34 520 and capacitor C23 522 expires. The system variables are initialised at step 500. The system variables fall into two categories, that is, device specific and application specific variables. The set up of the device specific variables includes configuration of the port lines PB0 to PB7 of the microcontroller 490. The configuration is required to ensure the correct input/output combination. Further variables are configured such that the internal counter/timer triggers an interrupt in the event of an overflow. Further details relating to the configuration of the variables used by the microcontroller are shown in the code of Table 2. Table 2 shows the multi-instruction software which is executed by the microcontroller.

The initialisation step 500 also configures the application specific variables which include disabling the lamp driver stage via port line "PB4" of microcontroller 490 and selection of an initial start up operating frequency which is above the pre-heating frequency. After initialisation there is preferably a brief delay introduced at step 502 to allow the product hardware to stabilise. Upon expiry of the delay, the status of the low voltage detector is determined via port line "PB1" of microcontroller 490 at step 504. If the low voltage detector 500 indicates that the supply voltage, V_{input}, is above the pick up threshold, control proceeds to step 506. However, if the low voltage detector 500 indicates that the supply voltage is below the pick up threshold, the step of determining, that is, step 504, is repeated until the supply voltage, V_{input}, exceeds the low voltage detector pick up voltage.

As indicated earlier for a vehicle system based on a nominal voltage of 110V DC, the pick up voltage would be selected as 67V and the drop-out voltage would be selected as 60V. The voltages are selected to prevent excessive discharge of the vehicle back-up battery in the event of a power failure such as a loss of overhead line voltage for an electric locomotive or loss of alternator charge voltage for a diesel locomotive. In the absence of this feature, the lights would be operated irrespective of battery discharge level resulting in lack of power for other essential train features and also possibly causing battery damage.

Once the low voltage detection criteria has been satisfied, the output frequency is set to that required for pre-heating, F_p, and the lamp driver stage is enabled which results in flow of a pre-heating current in the lamp electrodes, at step 508. In an embodiment, for a 58 Watt, T8, 1500 mm lamp and the resonant components of figure 4, the preheating frequency, F_p is 59.5 kHz. The pre-heating duration is under software control and is selected together with the

pre-heat current to attain thermionic emission within the electrodes. Table 1 below illustrates pre-heat currents and durations for various lamps which all comply with EN60081.

Lamp	Pre-heat current, mA (RMS)	Pre-heat duration, sec.	Arc Current, mA(RMS)	Strike Voltage, V (RMS)
70 Watt, T8 lamp, krypton gas	980	1	470	≥ 465
58 Watt, T8 lamp, krypton gas	850	1	455	≥ 335
36 Watt, T8 lamp, krypton gas	717	1	320	≥ 330
18 Watt, T8 lamp, krypton gas	620	1	290	≥ 280
15 Watt, T8 lamp, krypton gas	460	1	290	≥ 280

TABLE 1

The lamp driver stage is enabled at step 508. The microcontroller 490 then waits until expiry of the pre-heat period at 510. The pre-heat period is measured using the internal counter.

After expiry of the pre-heat period, the frequency output by the lamp driver unit is progressively reduced using a predetermined decrement until the output frequency corresponds to that required for strike voltage generation, that is, F_s. In a preferred embodiment, the magnitude of the frequency decrement is 1 kHz. Further, in an embodiment, for a 58 Watt, T8, 1500 mm lamp and the resonant components of figure 4, the strike voltage generation frequency, F_s, is 50 kHz. It will be appreciated that as the output frequency is reduced, the lamp

strike voltage will increase. The frequency is progressively reduced by steps 512 and 514. Due to prevailing ambient temperature conditions, the lamp may strike before the output frequency is reduced to the target strike voltage generation frequency, F_s.

For low temperature conditions, it is quite often the case that full strike voltage may be required. A determination is made at step 516 via the $\overline{STK}$ signal present on port line PB5 of microcontroller 490 whether the lamp has struck. If the lamp fails to strike, a determination is made at step 518 as to whether or not the most recent strike attempt is the last attempt via a variable, which is decreased until it is zero, that reflects the number of remaining strike attempts. This variable is also initialised at step 500. In a preferred embodiment, three strike attempts are allowed before lamp fail shut down occurs.

If it is determined at step 518 that the maximum number of strike attempts has been made, lamp fail shut down is arranged at step 520.

If it is determined at step 518 that there are remaining strike attempts, a delay of a predetermined duration is incurred before making any further strike attempts to allow the electrodes to cool down, that is, to prevent overheating of the electrodes, at 522. In a preferred embodiment, the cool down period has a duration of four seconds. However, the cool down period can be a little as one second.

After expiry of the cool down period, control returns to step 506 and the process of pre-heat and strike attempt is repeated.

If at step 516 it is determined that the lamp has struck, the output frequency is set to equal the running or operating frequency, F_{run}, at step 524. In an embodiment, for a 58 Watt, T8, 1500 mm lamp and the resonant components of figure 4

(resonant at 41.4 kHz), the operating frequency, F_{run}, is 48.07 kHz.

The microcontroller, having set the operating frequency, enters a loop within which there are made repeated determinations as to whether or not the lamp is still struck, at step 526, and whether or not the supply voltage is above a predetermined minimum level at step 528. The determination whether or not the lamp is still struck at step 526 is made by monitoring the arc current using the lamp struck detector 494 and the lamp L/C output circuitry 496. If it is determined that the lamp has extinguished, control is transferred to step 518 were a determination is made as to whether or not further strike attempts are permissible. It will be appreciated that the variable governing the number of remaining strike attempts is decremented every time a strike attempt fails or the lamp extinguishes.

If it is determined at step 528 that the input voltage, V_{input}, has fallen below the drop-out threshold, the output of the lamp is disabled at step 530 via a signal $\overline{SD}$. Control is then passed to step 504 where a determination is made repeatedly as to whether or not the supply voltage is above the minimum threshold level.

There is also shown in figure 5 the interrupt service routine. Upon entry into the interrupt service routine all registers are pushed onto a stack at step 532. The timer value is set at step 534. At step 536, the clock pin status is inverted, that is, toggled. The register values that were previously pushed onto the stack at step 532 are pulled from the stack at step 538 whereupon control then returns to the main routine at step 540.

A further embodiment also provides a dimming function which is realised by varying the operating frequency, F_{run}, and thus the arc current once the lamp has struck. The variation in arc current causes a variation in lamp power which in turn

determines light output. In an embodiment, the light output can be reduced to 20% of maximum.

By precise control of the resonant L3/C17 network drive frequency using the microcontroller it is possible to control very accurately the pre-heat current, strike voltage and arc current. Such accurate control results in improved lamp life and improved and consistent light output levels and colour.

A further embodiment of the present invention provides a lamp drive unit comprising an EEPROM. The EEPROM is utilised to record the operational history of the lamp performance. This operational history may record events such as number of lamp strikes thus far, number of first attempt light strike failures and prevailing system conditions in the event of failure or erratic behaviour.

A further embodiment of the present invention can be realised to accommodate cold cathode lamps. To accommodate cold cathode lamps the steps associated with pre-heat are omitted and the step associated with the strike voltage is suitably modified so that an appropriate frequency is output to the L3/C17 resonant circuit.

It will be appreciated that an advantage of the present invention is that the light output intensity and colour can be closely controlled and matched. This is particularly important in situations where a plurality of lamps is used in a given environment. Furthermore, within the railway industry, where the lamps are used in rows within railway vehicle passenger saloons, the impression of a continuous band of interrupted light is desirable.

The code for the microcontroller shown in Table 2 below is arranged to control the lamp driver unit to operate correctly a 58 Watt, 1500 mm, T8 lamp.

CLAIMS

1. A lamp driver unit comprising a software controlled microcontroller arranged to execute software to generate an output waveform having a selectable one of a plurality of predeterminable frequencies, a lamp drive means comprising at least one inductor and at least one capacitor arranged to produce a drive signal for the lamp in response to receiving the output waveform; the output waveform being derived from a programmable counter that is driven using an oscillator, the selectable one of the plurality of predeterminable frequencies being determined by count value of the programmable counter in response to data values contained within the software executed by the microcontroller.

2. A lamp driver unit as claimed in claim 1 in which the programmable counter constitutes means for dividing the oscillator waveform by a predeterminable divisor.

3. A lamp driver unit as claimed in claim 2 in which the means for dividing comprises a programmable counter arranged to vary the count action thereof in response to the oscillator waveform and the output waveform is produced in response to an output signal of the programmable counter.

4. A lamp driver unit as claimed in claim 3 in which the divisor is determined according to a predeterminable frequency.

5. A lamp driver unit as claimed in any preceding claim in which the predeterminable frequency is determined according to lamp type.

6. A lamp driver unit as claimed in any preceding claim in which the predeterminable frequency is determined according to a stage of operation of a lamp

7. A lamp driver unit as claimed in claim 6 in which the stage of operation is one of pre-heating, generating a strike voltage and maintaining an arc current waveform.

8. A lamp driver unit as claimed in any preceding claim in which the predeterminable frequency is selected from a plurality of frequencies.

9. A lamp driver unit as claimed in any preceding claim, wherein the inductor is connected in series with a capacitor, and the lamp drive means comprises means for receiving the lamp such that, in use, the lamp is connected in parallel with the capacitor.

10. A lamp driver unit as claimed in any preceding claim comprising means for heating the lamp electrodes prior to application of a strike voltage.

11. A lamp driver unit as claimed in claim 10 in which the means for heating heats the lamp electrodes to a point of thermionic emission.

12. A lamp driver unit as claimed in either of claims 10 and 11 in which the means for heating is arranged to heat the electrodes for a predetermined fixed period.

13. A lamp driver unit as claimed in claim 12 in which the predetermined fixed period is determined according to a pre-heat current for a lamp type.

14. A lamp driver unit as claimed in any preceding claim comprising means for ensuring an arc current waveform of the lamp has a predeterminable crest factor.

15. A lamp driver unit as claimed in claim 14 in which the crest factor is substantially 1.4.

16. A lamp driver unit as claimed in any preceding claim in which the drive signal comprises a substantially fully symmetrical arc drive current waveform.

17. A lamp driver unit as claimed in claim 16 in which the arc drive current waveform is a near-sine wave current waveform.

18. A lamp driver unit as claimed in any preceding claim in which at least one of the output waveform and the drive signal has a predeterminable drive frequency.

19. A lamp driver unit as claimed in any preceding claim in which the arc current is at least one of 470 mA, 455 mA, 320 mA, 290 mA or 290 mA.

20. A lamp driver unit as claimed in any preceding claim comprising means for maintaining a substantially stable arc current waveform.

21. A lamp driver unit as claimed in claim 20 in which the means for maintaining a substantially stable arc current waveform comprises means for maintaining the arc current waveform to within ±6% of a predeterminable arc current waveform.

22. A lamp driver unit as claimed in any preceding claim operable at predeterminable power conversion efficiencies.

23. A lamp driver unit as claimed in claim 22 in which the operating efficiencies are at least 84%.

24. A lamp driver unit as claimed in claim 23 in which the operating efficiencies are between 84% and 90%.

25. A lamp driver unit as claimed in any preceding claim comprising means arranged to provide a floating lamp drive output.

26. A lamp driver unit as claimed in either of claims 25 in which the means arranged to provide a floating lamp drive output comprises an output transformer wound for 2 kV

primary to secondary isolation.

27. A lamp driver unit as claimed in any preceding claim comprising means for electronically providing at least one protection feature.

28. A lamp driver unit as claimed in any preceding claim comprising means for preventing attempted re-strikes in the event of a failed lamp.

29. A lamp driver unit as claimed in any preceding claim comprising a cut-out means for inhibiting the use of a lamp upon detection of a falling supply voltage or a supply voltage that is below a predetermined level.

30. A lamp driver unit as claimed in claim 29 in which the cut-out means is provided with some hysteresis to avoid flickering as the supply voltage varies.

31. A lamp driver unit as claimed in any preceding claim comprising transient and surge suppression means.

32. A lamp driver unit substantially as described herein with reference to and/or as illustrated in the accompanying drawings.

33. A passenger vehicle comprising a lamp driver unit as claimed in any preceding claim.

34. A lamp and lamp driver unit as claimed in any preceding claim.

35. A computer program element for controlling a lamp driver unit substantially as described herein with reference to and/or as illustrated in the accompanying drawings.

36. A method for controlling an operating point of a lamp using a microcontroller executing software, the method comprising the steps of:

generating a waveform having a first frequency in

response to receipt of an oscillator signal of a predetermined frequency that is greater than the first frequency, the step of generating including varying the count of a programmable counter until a predetermined count, selectable from a plurality of predetermined counts, has elapsed and producing a change in the state of the waveform in response to the lapse of the predetermined count; and

driving an LC circuit comprising at least one inductor in series with a parallel arrangement of a lamp and a capacitor to maintain the operation of the lamp at the operating point.

37. A method as claimed in claim 36, in which the step of generating comprising the step of generating an interrupt in response to the elapse of a predetermined count, calling an interrupt routine of the software in response to the generation of the interrupt, which interrupt routine produces the change in state of the waveform.

38. A method as claimed in either of claims 36 or 37, further comprising the step of resetting the programmable counter to the predetermined count in response to predetermined count having lapsed.

39. A method as claimed in any of claims 36 to 39, further comprising the step selecting, in turn, all of the predetermined counts in a desired sequence.

40. A method as claimed in any of claims 36 to 39 in which at least one of the predetermined count or predetermined counts are established in conjunction with the oscillator frequency according to corresponding required frequencies of oscillation of the waveform.

41. A method for operating a lamp substantially as described

herein with reference to and/or as illustrated in the accompanying drawings.

42. A computer program element for controlling an operating point of a lamp using a microcontroller executing software, the element comprising

computer program code means for generating a waveform having a first frequency in response to receipt of an oscillator signal of a predetermined frequency that is greater than the first frequency, the including computer program code means for varying the count of a programmable counter until a predetermined count, selectable from a plurality of predetermined counts, has elapsed and computer program code means for producing a change in the state of the waveform in response to the lapse of the predetermined count; and

computer program code means for driving an LC circuit comprising at least one inductor in series with a parallel arrangement of a lamp and a capacitor to maintain the operation of the lamp at the operating point.

43. An element as claimed in claim 42, in which the computer program code means for generating comprises computer program code means for generating an interrupt in response to the elapse of a predetermined count, computer program code means for calling an interrupt routine of the software in response to the generation of the interrupt, which interrupt routine produces the change in state of the waveform.

44. An element as claimed in either of claims 42 or 43, further comprising computer program code means for resetting the programmable counter to the predetermined count in response to predetermined count having lapsed.

45. An element as claimed in any of claims 42 to 44, further comprising computer program code means for selecting, in turn, all of the predetermined counts in a desired sequence.

46. An element as claimed in any of claims 42 to 45 in which at least one of the predetermined count or predetermined counts are established in conjunction with the oscillator frequency according to corresponding required frequencies of oscillation of the waveform.

47. A computer program element substantially as described herein with reference to and/or as illustrated in the accompanying drawings.

48. A computer program product having stored thereon or therein a computer program element as claimed in any of claims 42 to 47.

49. A computer program product as claimed in claim 48 in which the product is or comprises non-volatile storage for the computer program element.

50. A computer program product as claimed in either of claims 48 and 49 in which the non-volatile storage is contained with the microcontroller.

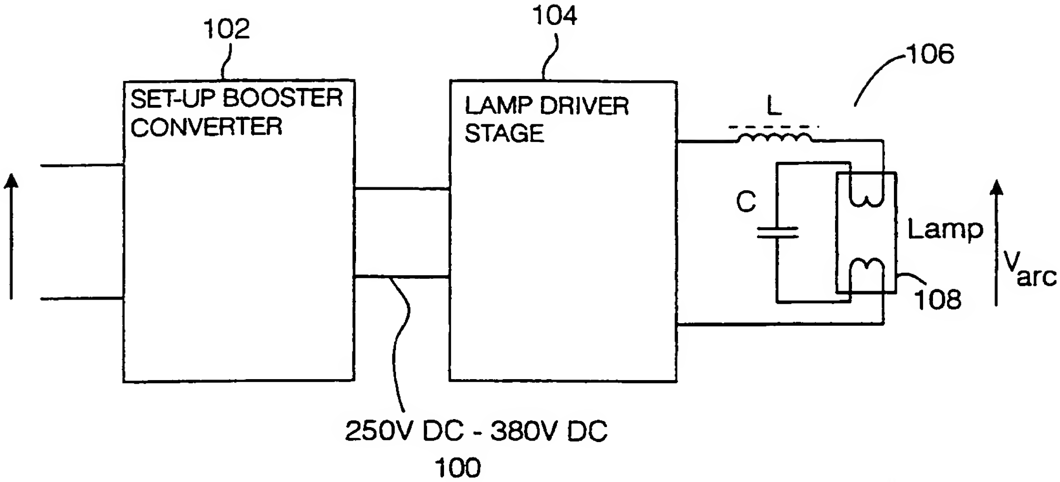

102
SET-UP BOOSTER CONVERTER
104
LAMP DRIVER STAGE
106
L
C
Lamp
108
Varc
250V DC - 380V DC
100

Fig. 1

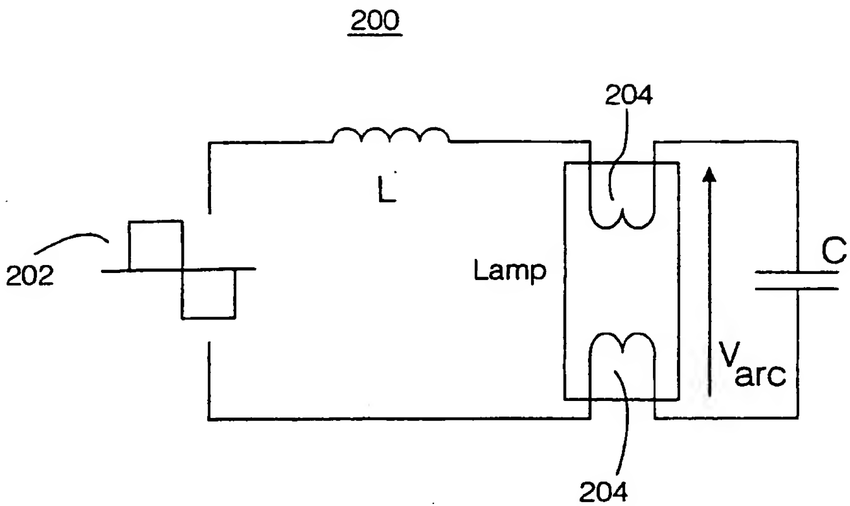


Fig. 2

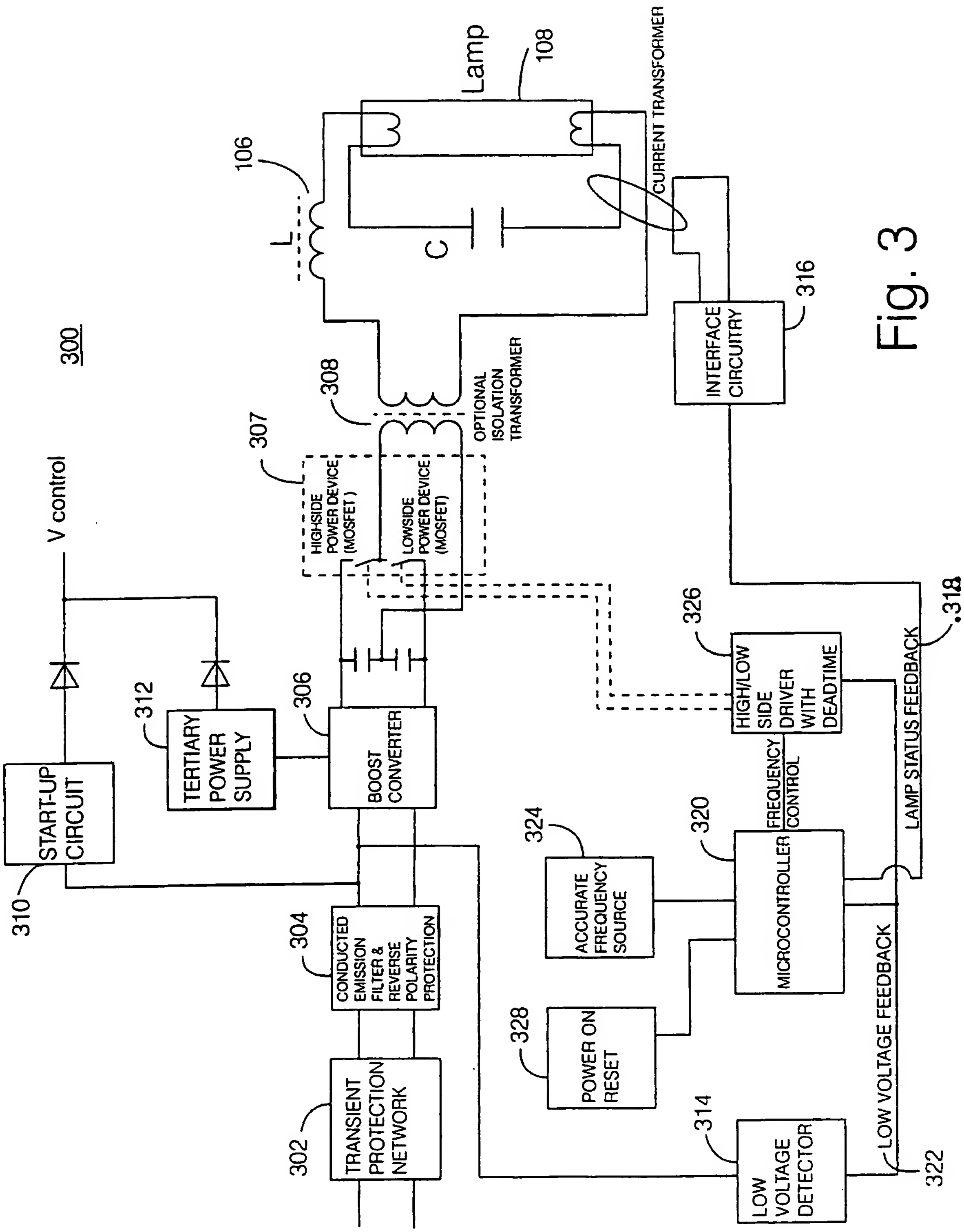

300
V control
START-UP CIRCUIT
310
TERTIARY POWER SUPPLY
312
BOOST CONVERTER
306
HIGHSIDE POWER DEVICE (MOSFET)
LOWSIDE POWER DEVICE (MOSFET)
307
308
OPTIONAL ISOLATION TRANSFORMER
L
106
C
Lamp
108
CURRENT TRANSFORMER
INTERFACE CIRCUITRY
316
CONDUCTED EMISSION FILTER & REVERSE POLARITY PROTECTION
304
TRANSIENT PROTECTION NETWORK
302
ACCURATE FREQUENCY SOURCE
324
POWER ON RESET
328
MICROCONTROLLER
320
FREQUENCY CONTROL
HIGH/LOW SIDE DRIVER WITH DEADTIME
326
LAMP STATUS FEEDBACK
318
LOW VOLTAGE FEEDBACK
322
LOW VOLTAGE DETECTOR
314

Fig. 3

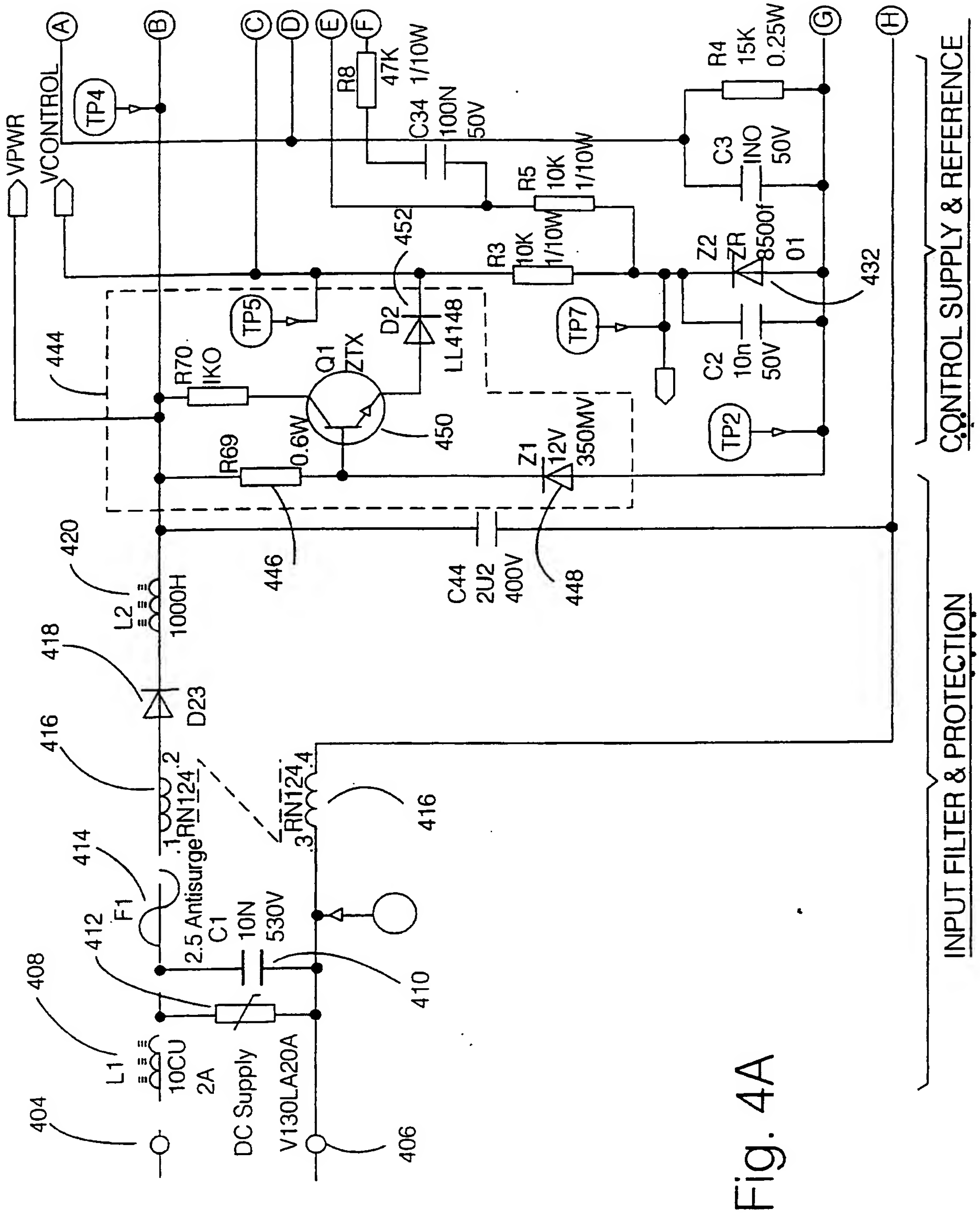

VPWR
VCONTROL
A
B
C
D
E
F
G
H
TP4
TP5
TP7
TP2
R8
47K
1/10W
C34
100N
50V
R5
10K
1/10W
R4
15K
0.25W
C3
INO
50V
452
R3
10K
1/10W
Z2
ZR
8500f
01
432
444
R70
IKO
Q1
ZTX
D2
LL4148
450
R69
0.6W
Z1
12V
350MV
C2
10n
50V
420
L2
1000H
446
C44
2U2
400V
448
418
D23
416
RN124
.1
.2
.3
.4
414
F1
2.5 Antisurge
C1
10N
530V
412
408
L1
10CU
2A
DC Supply
V130LA20A
404
406
410
CONTROL SUPPLY & REFERENCE
INPUT FILTER & PROTECTION

Fig. 4A

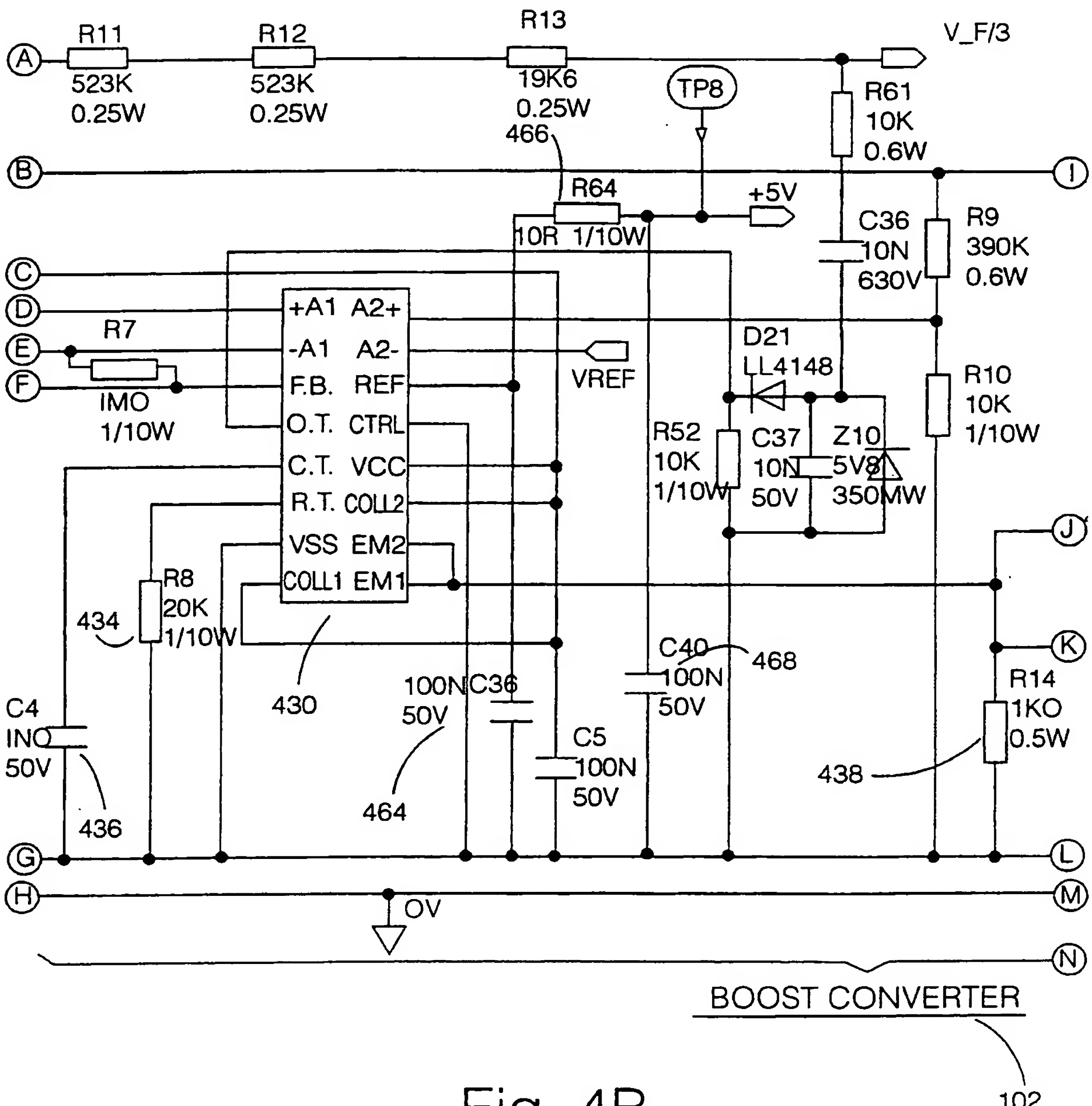

R11
523K
0.25W
R12
523K
0.25W
R13
19K6
0.25W
466
V_F/3
TP8
R61
10K
0.6W
R64
10R 1/10W
+5V
C36
10N
630V
R9
390K
0.6W
R7
IMO
1/10W
+A1 A2+
-A1 A2-
F.B. REF
O.T. CTRL
C.T. VCC
R.T. COLL2
VSS EM2
COLL1 EM1
VREF
D21
LL4148
R10
10K
1/10W
R52
10K
1/10W
C37
10N
50V
Z10
5V6
350MW
R8
20K
1/10W
434
430
C40
100N
50V
468
100N C36
50V
C5
100N
50V
R14
1KO
0.5W
C4
INO
50V
436
464
438
OV
A
B
C
D
E
F
G
H
I
J
K
L
M
N
BOOST CONVERTER
102

Fig. 4B

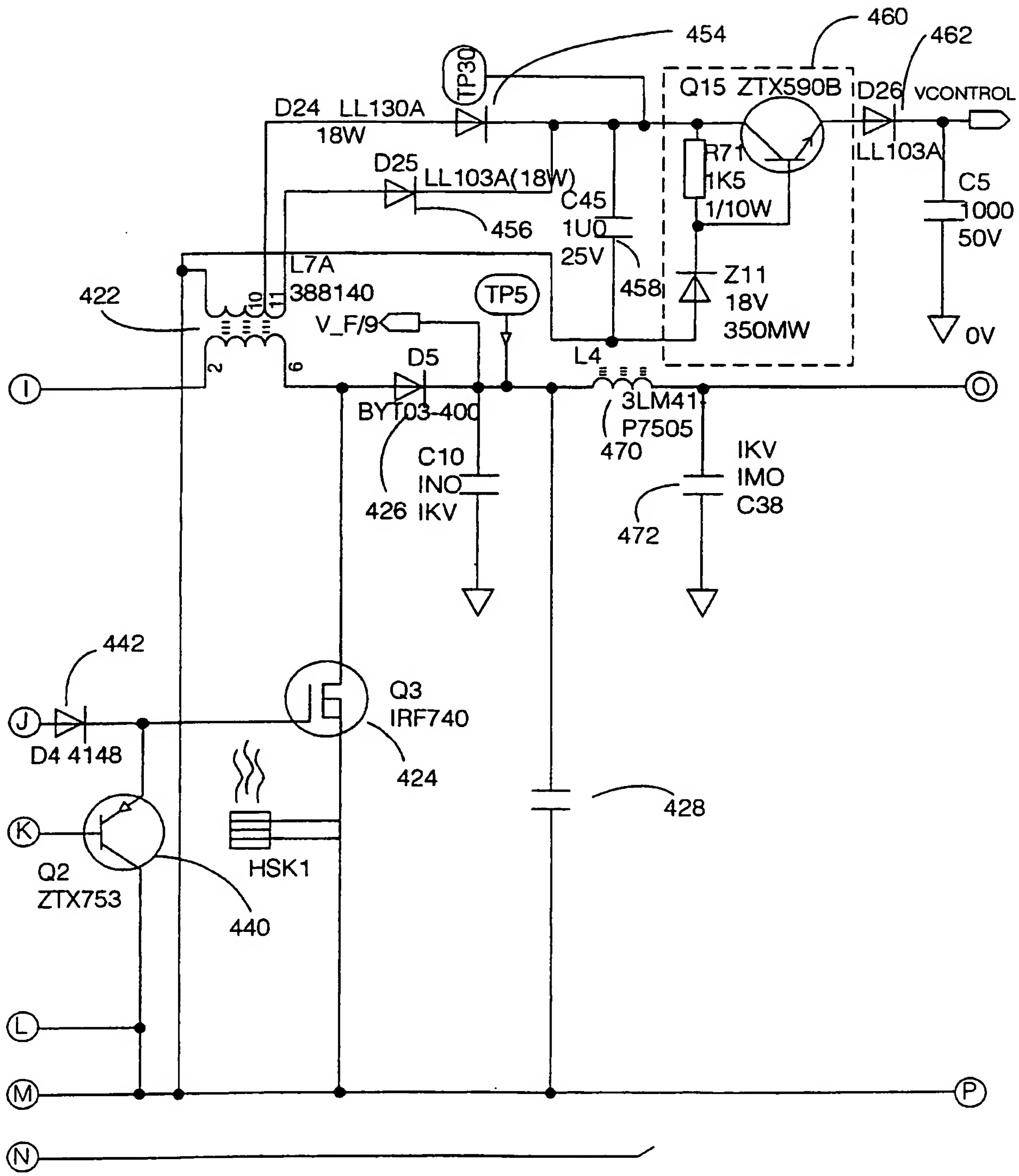

454
460
462
TP30
Q15 ZTX590B
D26
VCONTROL
D24 LL130A
18W
R71
1K5
1/10W
LL103A
D25
LL103A(18W)
C45
1U0
25V
C5
1000
50V
456
458
L7A
388140
Z11
18V
350MW
422
TP5
V_F/9
0V
2
6
10
11
D5
L4
3LM41
P7505
BYT03-400
470
I
O
C10
IN0
426 IKV
IKV
IMO
C38
472
442
Q3
IRF740
J
D4 4148
424
K
428
HSK1
Q2
ZTX753
440
L
M
P
N

Fig. 4C

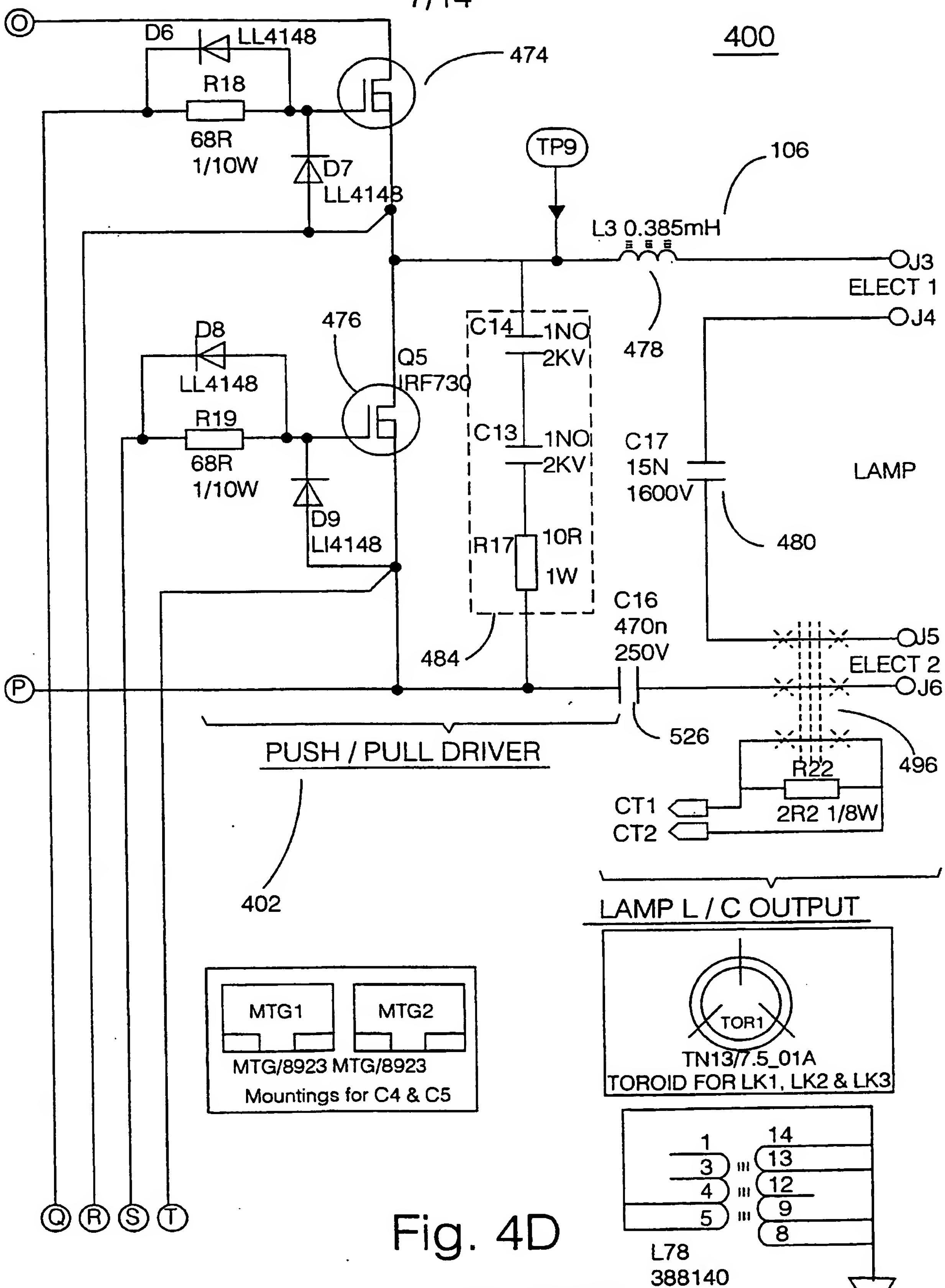

400
O
D6
LL4148
R18
68R
1/10W
474
D7
LL4148
TP9
106
L3 0.385mH
J3
ELECT 1
J4
478
476
D8
LL4148
R19
68R
1/10W
Q5
IRF730
D9
LI4148
C14
1NO
2KV
C13
1NO
2KV
R17
10R
1W
C17
15N
1600V
LAMP
480
C16
470n
250V
J5
ELECT 2
J6
P
484
526
496
PUSH / PULL DRIVER
R22
2R2 1/8W
CT1
CT2
402
LAMP L / C OUTPUT
MTG1
MTG2
MTG/8923 MTG/8923
Mountings for C4 & C5
TOR1
TN13/7.5_01A
TOROID FOR LK1, LK2 & LK3
1
3
4
5
14
13
12
9
8
L78
388140
Q
R
S
T

Fig. 4D

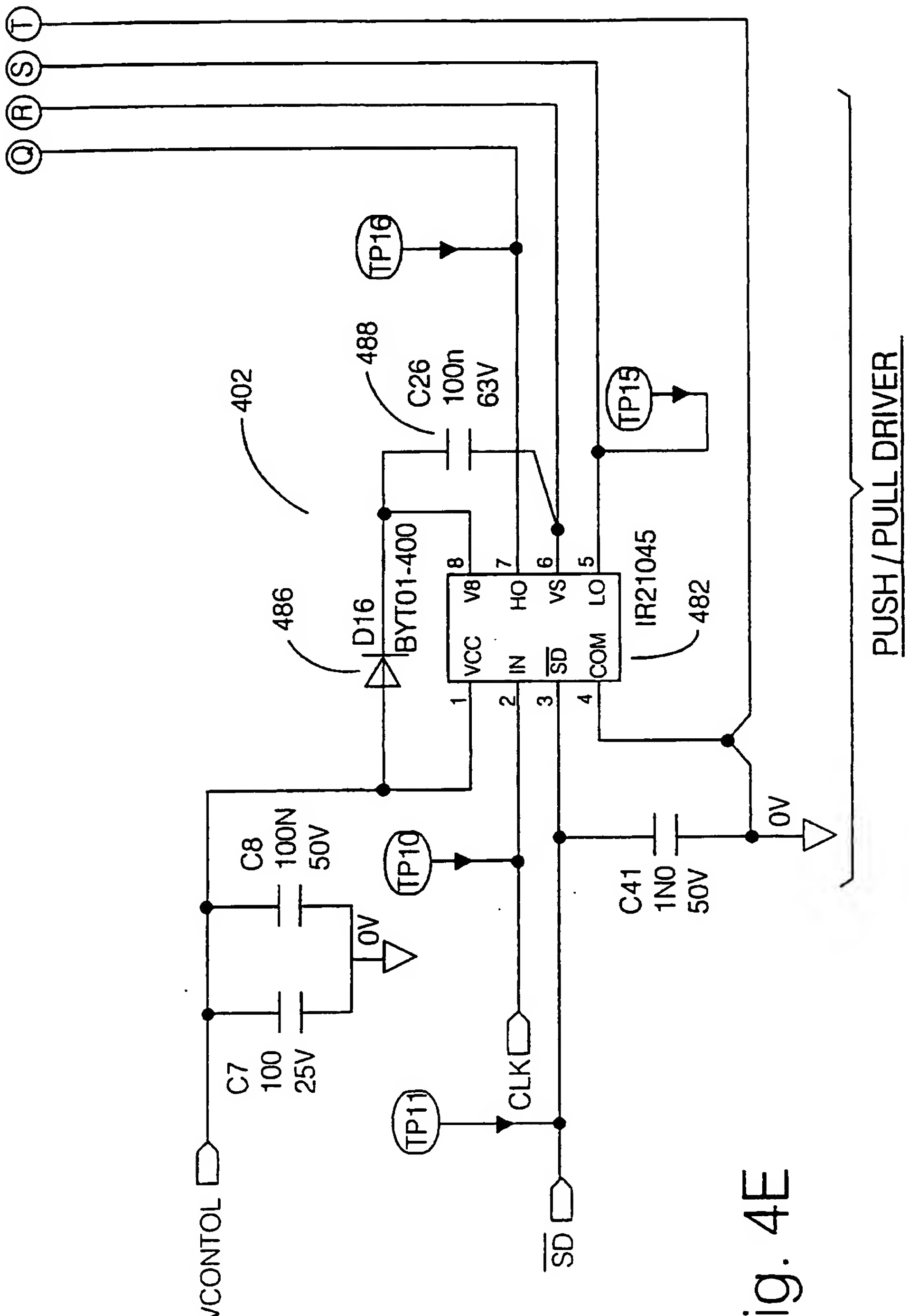

Q
R
S
T
TP16
TP15
TP10
TP11
488
C26
100n
63V
402
486
D16
BYT01-400
8
7
6
5
1
2
3
4
VB
HO
VS
LO
VCC
IN
SD
COM
IR21045
482
PUSH / PULL DRIVER
0V
C41
1N0
50V
C8
100N
50V
C7
100
25V
CLK
VCONTOL
SD

Fig. 4E

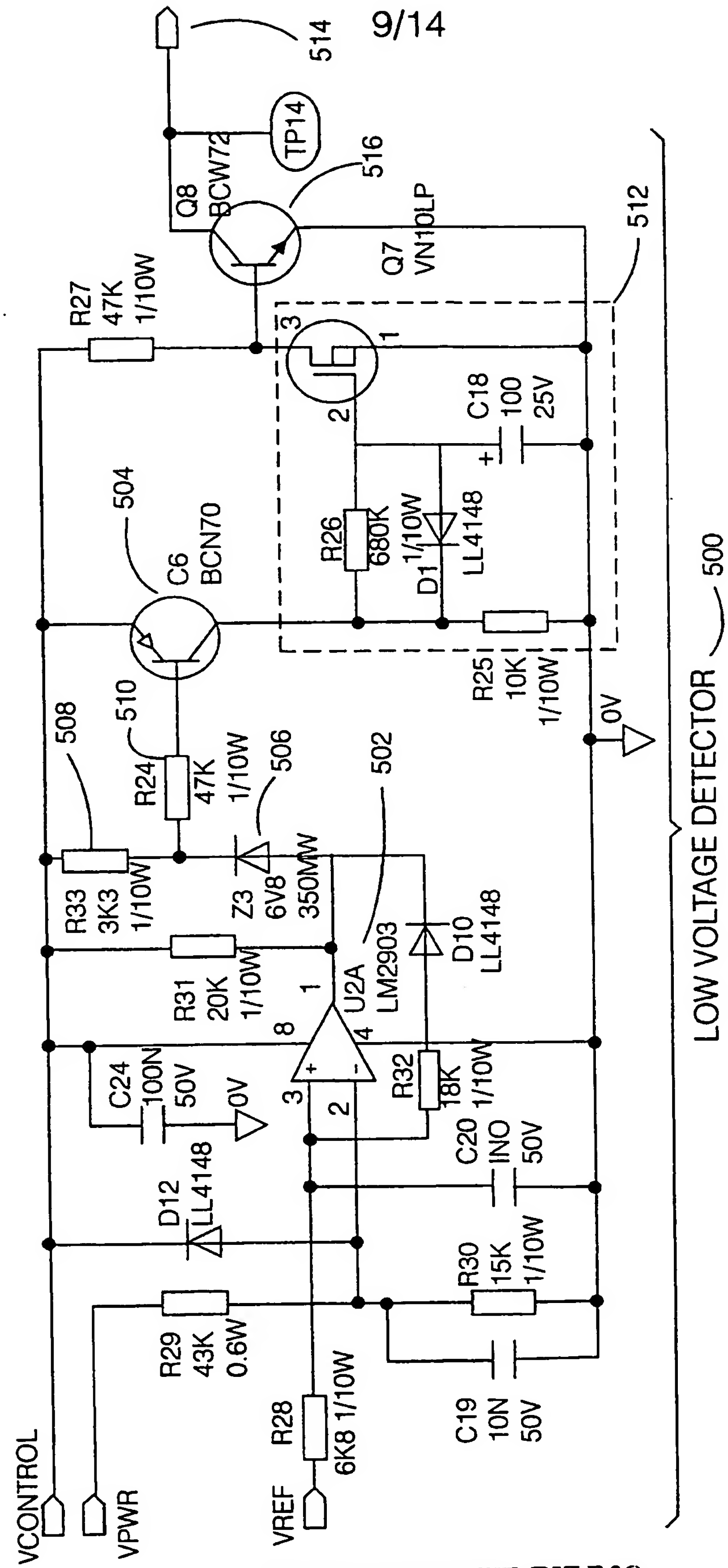

514
TP14
516
Q8
BCW72
Q7
VN10LP
512
R27
47K
1/10W
504
C6
BCN70
R26
680K
1/10W
D1
LL4148
C18
100
25V
R25
10K
1/10W
0V
508
510
R24
47K
1/10W
506
502
R33
3K3
1/10W
Z3
6V8
350MW
R31
20K
1/10W
U2A
LM2903
D10
LL4148
C24
100N
50V
R32
18K
1/10W
C20
1NO
50V
D12
LL4148
R30
15K
1/10W
R29
43K
0.6W
R28
6K8 1/10W
C19
10N
50V
VCONTROL
VPWR
VREF
LOW VOLTAGE DETECTOR
500

Fig. 4F

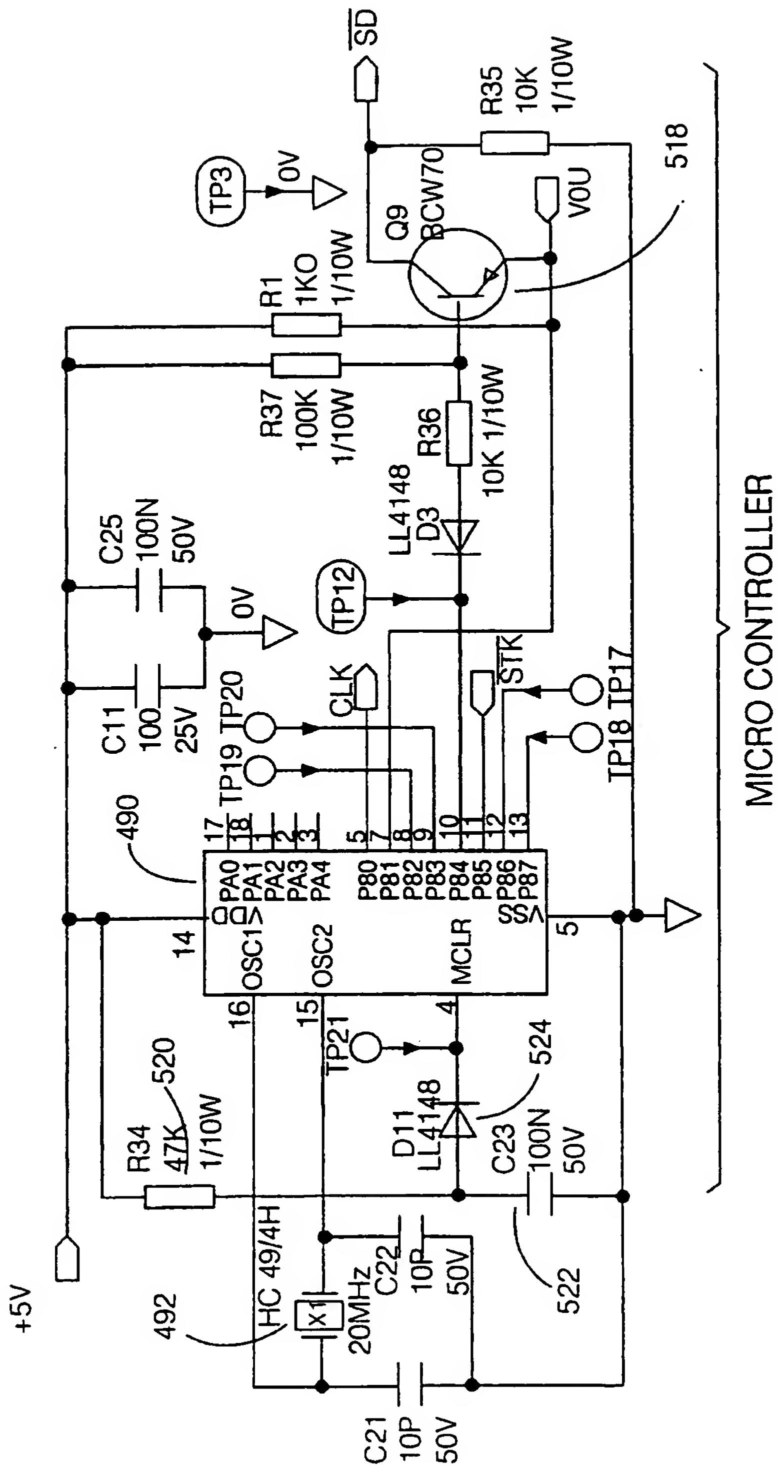

SD
TP3
0V
R35
10K
1/10W
518
Q9
BCW70
V0U
R1
1KO
1/10W
R37
100K
1/10W
R36
10K 1/10W
LL4148
D3
C25
100N
50V
TP12
C11
100
25V
TP20
TP19
CLK
STK
TP18
TP17
490
PA0
PA1
PA2
PA3
PA4
P80
P81
P82
P83
P84
P85
P86
P87
OSC1
OSC2
MCLR
TP21
D11
LL4148
524
C23
100N
50V
R34
47K
1/10W
520
+5V
492
HC 49/4H
X1
20MHz
C22
10P
50V
522
C21
10P
50V
MICRO CONTROLLER

Fig. 4G

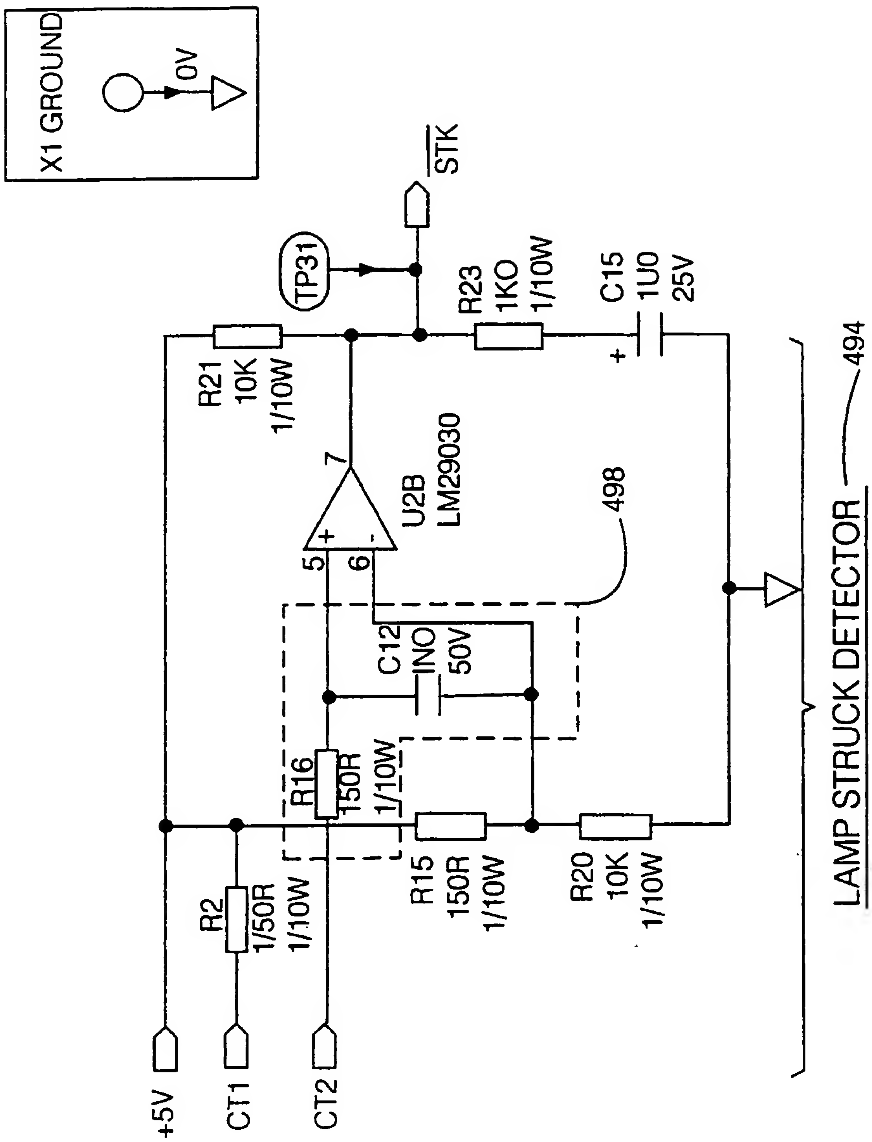

X1 GROUND
0V
STK
TP31
R23
1KO
1/10W
C15
1U0
25V
R21
10K
1/10W
7
U2B
LM29030
498
5
6
C12
INO
50V
R16
150R
1/10W
R15
150R
1/10W
R20
10K
1/10W
R2
1/50R
1/10W
+5V
CT1
CT2
LAMP STRUCK DETECTOR
494

Fig. 4H

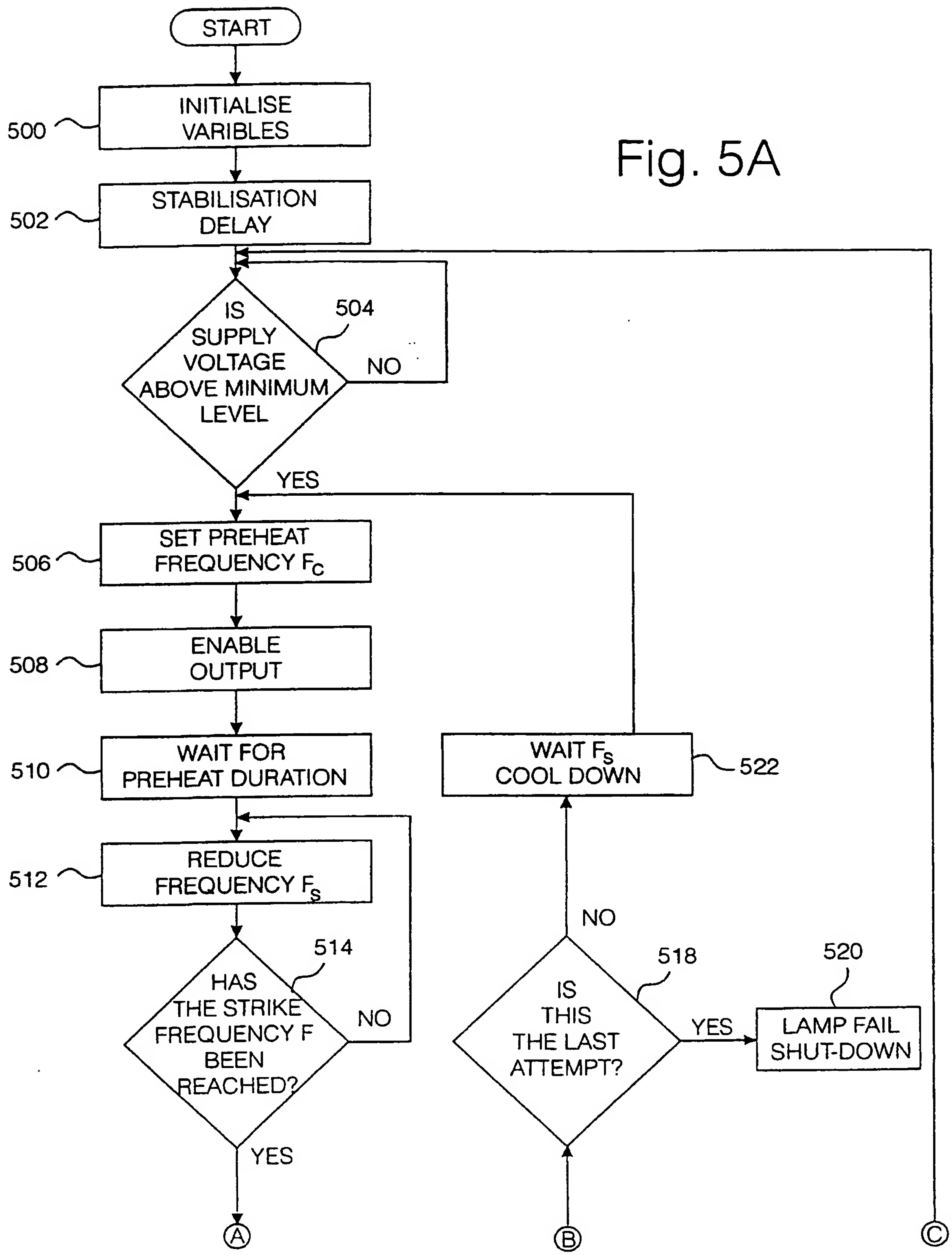

START
500
INITIALISE VARIBLES
502
STABILISATION DELAY
504
IS SUPPLY VOLTAGE ABOVE MINIMUM LEVEL
NO
YES
506
SET PREHEAT FREQUENCY F_C
508
ENABLE OUTPUT
510
WAIT FOR PREHEAT DURATION
512
REDUCE FREQUENCY F_S
514
HAS THE STRIKE FREQUENCY F BEEN REACHED?
NO
YES
A
522
WAIT F_S COOL DOWN
NO
518
IS THIS THE LAST ATTEMPT?
YES
520
LAMP FAIL SHUT-DOWN
B
C

Fig. 5A

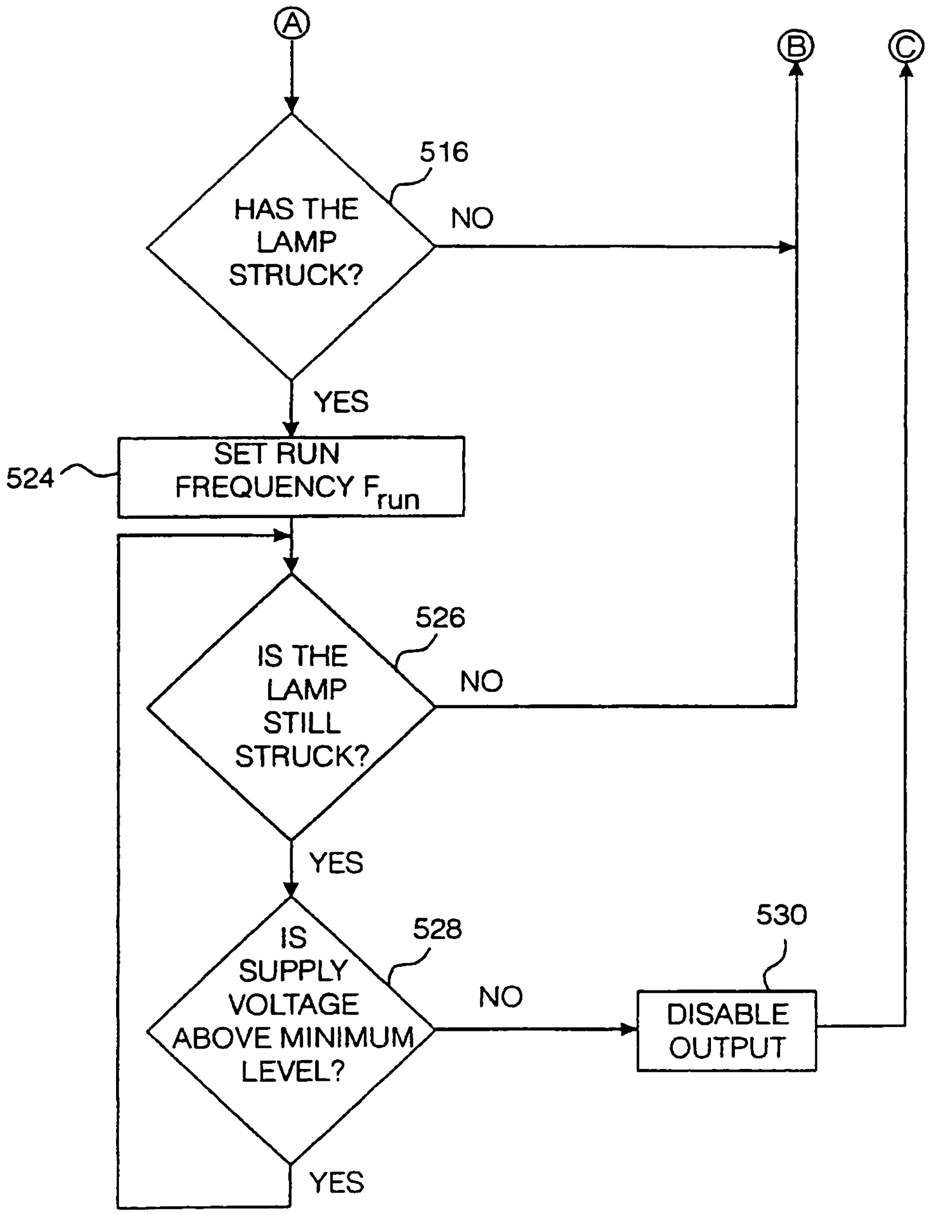
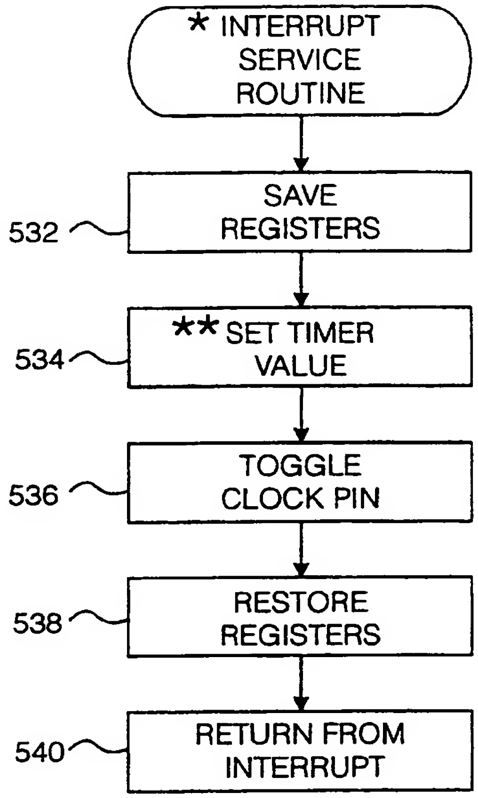

A
B
C
516
HAS THE LAMP STRUCK?
NO
YES
524
SET RUN FREQUENCY F_{run}
526
IS THE LAMP STILL STRUCK?
NO
YES
528
IS SUPPLY VOLTAGE ABOVE MINIMUM LEVEL?
NO
YES
530
DISABLE OUTPUT

Fig. 5B



* THIS ROUTINE IS ENTERED WHEN THE TIMER OVERFLOWS.

** THE TIMER VALUE SETS THE OUTPUT FREQUENCY. THIS VALUE IS DETERMINED DURING PROGRAM FLOW.

Fig. 5C

INTERNATIONAL SEARCH REPORT

Intern ıal Application No
PCT/GB 00/02994

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 H05B41/36 H05B41/298

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 H05B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5 925 990 A (CROUSE KENT E ET AL) 20 July 1999 (1999-07-20)	1-13,16, 18-20, 22,27,28
A	abstract; figures column 2, line 6 - line 63 column 5, line 1 - line 37 column 9, line 1 - line 17 claims ---	29-50
X	EP 0 413 991 A (TOSHIBA LIGHTING & TECHNOLOGY) 27 February 1991 (1991-02-27)	1-10,16, 18,20, 25,27
A	abstract column 3, line 57 -column 4, line 41 column 6, line 3 - line 30 column 6, line 58 -column 7, line 7 claims ---	32-50

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

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"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 November 2000	17/11/2000

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Maicas, J.

2

INTERNATIONAL SEARCH REPORT

Intern al Application No
PCT/GB 00/02994

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 338 109 A (ZUMTOBEL AG) 25 October 1989 (1989-10-25)	1-4, 6-13, 16-18, 20,27-30
A	abstract; figure column 4, line 53 -column 8, line 37 claims	31-50
P,A	US 5 973 455 A (CROUSE KENT E ET AL) 26 October 1999 (1999-10-26) figure 2 column 3, line 65 - line 67 column 4, line 28 -column 5, line 32	1-50
A	EP 0 178 852 A (THOMAS INDUSTRIES INC) 23 April 1986 (1986-04-23) abstract	14-17

2

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No
PCT/GB 00/02994

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5925990 A	20-07-1999	AU 1827199 A	12-07-1999
		EP 1040399 A	04-10-2000
		WO 9932953 A	01-07-1999
EP 0413991 A	27-02-1991	JP 2045674 C	25-04-1996
		JP 3059995 A	14-03-1991
		JP 7066864 B	19-07-1995
		KR 9311849 B	21-12-1993
		US 5039921 A	13-08-1991
EP 0338109 A	25-10-1989	AT 103458 T	15-04-1994
		DE 3888675 D	28-04-1994
		DE 3913033 A	16-11-1989
		DK 188089 A	21-10-1989
		FI 891828 A,B,	21-10-1989
		NO 177520 B	19-06-1995
		NO 950633 A,B,	23-10-1989
US 5973455 A	26-10-1999	WO 9960825 A	25-11-1999
EP 0178852 A	23-04-1986	US 4658187 A	14-04-1987
		AT 104104 T	15-04-1994
		AU 596079 B	26-04-1990
		AU 4841585 A	24-04-1986
		CA 1333408 A	06-12-1994
		DE 3587792 D	11-05-1994
		DE 3587792 T	13-10-1994
		JP 61096699 A	15-05-1986
		US 4723098 A	02-02-1988